NASA TECHNICAL TRANSLATION

NASA TT F-533

NASA TT F-533

C. 1

THE FACE OF THE EARTH AND ITS ORIGIN

by G. N. Katterfel'd

State Publishing House of Geographical Literature
Moscow, 1962

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION • WASHINGTON, D. C. • JUNE 1969

NASA TT F-533

THE FACE OF THE EARTH AND ITS ORIGIN

By G. N. Katterfel'd

Translation of "Lik Zemli i ego Proiskhozhdeniye"
State Publishing House of Geographical Literature,
Moscow, 1962

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

For sale by the Clearinghouse for Federal Scientific and Technical Information
Springfield, Virginia 22151 – CFSTI price $3.00

Table of Contents

THE FACE OF THE EARTH AND ITS ORIGIN

G. N. Katterfel'd

ABSTRACT: The earth is subject to deforming forces derived, on the one hand, from its rotation, and, on the other, from alternate compression and expansion of the terrestrial body (pulsation), associated with the action of gravity and with that of internal physico-chemical reactions. The net result of the interaction of these forces over the course of enormous periods of time has been the establishment of lines of maximal stress which have given rise to tectonic movements in the mantle. This has led to the well-known "antipodal" character of terrestrial relief: land masses (elevations) on one side of the globe are counterbalanced by water masses (depressions) on the other; and also to a number of other peculiarities, such as the wedge shape exhibited by the continents, and the distribution of volcanic activity. It is believed that the tidal action of the moon (which originated in nearby space at the same time as the earth) was an important factor leading to the imbalance in terrestrial relief.

Annotation:

In this book are discussed the very largest forms of terrestrial relief--the continents, oceanic troughs and mountain belts--as well as their origin, peculiarities of distribution, similarities and differences. /2*

The author explains why the dry-land areas of our planet are concentrated mainly in the Northern and Eastern Hemispheres, and the oceans in the Southern and Western; why every ocean is "balanced" by a continent on the opposite side of the globe; why the continents (and hence also the oceans) are wedge-shaped, and so forth.

While intended primarily for students of geography and geology, as well as scientists working in the fields of planetary physiography, geotectonics, and general planetology, this book will also be of interest to all those seeking to enlarge their knowledge of our native planet, which in many respects remains enigmatical and little known.

Artist: L. I. Falin

*Numbers in the margin indicate pagination in the foreign text.

/3

Author's Remarks:

In our day, geological science is at great pains to describe the changes which take place on the surface of the earth and within its component parts, but it supplies no answer to the question of what brought about the formation and present-day distribution of the major forms of terrestrial relief--the oceans, continents and mountain belts. In particular, geology says nothing about so surprising a feature of our planet as the concentration of oceans in the Western and Southern Hemispheres, and the concentration of continents in the Eastern and Northern.

And yet, the elucidation and explanation of the laws governing the distribution of the major forms of terrestrial relief and of the planetary structures of the lithosphere are no less important than the study of the processes whereby those structures came into existence. It may well be that those laws are not peculiar to our own planet. Let us recall that long ago a remarkable planetary homology between the earth and Mars was pointed out--the existence of a great "southern ocean" on each planet which extends its bays and seas toward the north.

Despite the fact that earlier attempts to formulate these cardinal laws (Lowthian Green, 1875-1887, W. Pickering, 1907) were not successful, not a single subsequent contribution to world geological literature has been made on this important subject. This deficiency is understandable, first of all in view of the fact that these questions, however long they may have interested natural scientists and geographers, are unquestionably among the most difficult /4 to analyze. Secondly, in their study of planetary tectonic problems, investigators have made only the scantiest use of the results obtained in sciences adjacent to geology and geography--namely, astronomy, geodetics, celestial mechanics, geophysics and geochemistry. Any attempt to construct a theory of the earth on the basis of geology and geography alone, without recourse to the other sciences referred to, is inevitably doomed to failure.

It is therefore, not surprising that in our day--an era when the fantastic is becoming real in the world of physical science and technology--we are without a satisfactory general theory of tectonics.

But at least the bases for such a theory exist and are being developed: I refer to the pulsational, rotational and differentiational hypotheses. The first dates from the work of R. Richthofen (1869), the second from the work of G. H. Darwin (1879) and W. Taylor (1885). The elements of all three hypotheses were first combined by the eminent Russian scientist Ye. V. Bykhanov, in 1877.

Underlying the pulsational hypothesis advanced by the New York geologist-professor W. Bucher (1933, 1939) is the concept of alternating compressions and expansions (pulsations) of the volume of our planet, with a dominant role being played by compression. In justifying and developing this hypothesis, a particularly important contribution was made by the Soviet scientists M. A. Usov (1935, 1936, 1940), V. A. Obruchev (1940), and (as regards its application to the moon) A. V. Khabakov (1949).

The rotational hypothesis was created by A. Bem (1910), then professor of geography at Chernovtsy University, H. Quiring (1921), and M. V. Stovas, docent of the Dnepropetrovsk Mining Institute, who, beginning with 1951, concerned himself with the mathematical foundations of the hypothesis. This hypothesis is based on the fact of secular (resulting from tidal friction) and oscillatory variations in the earth's rotational velocity, and on the pulsations in the figure of the earth which are associated with those variations. Our most eminent geologists, A. P. Karpinskiy, F. Yu. Levinson-Lessing, and A. V. Khabakov, among the factors of tectogenesis, have placed particular stress upon the role of such dynamic-astronomical phenomena as the axial rotation of the planet. Levinson-Lessing in 1923, in his *The Universe and Geology*, wrote that there are two causes underlying dislocation processes /5
which are most deserving of attention: "...(1) displacement of the poles, and (2) displacement of masses within the earth, these being accompanied by changes in the earth's rotational velocity, a shift in the aqueous shell of the earth, and variation in terrestrial flatness. Every displacement of the poles, every displacement of masses within the earth, accompanied by changes in the distribution of gravitational stress, unquestionably results in stresses which lead to deformations, fractures, and shifts. That is precisely the reason why any change in rotational velocity... must result not only in the removal of waters from certain latitudes under the effect of acceleration, and the influx of waters into the polar regions under the effect of deceleration, but also in the deformation of the very body of the earth--as is indicated to us by the fact of earthquakes..." (pp. 142 - 143). One of the most active proponents of the theory of the geological development of the earth based on gravity and axial rotation and the relationship between the earth, moon and sun, is (as of 1931) Prof. B. L. Lichkov of Leningrad University.

As regards the differentiational hypothesis worked out by V. V. Beulousov (1954, 1955) and van Bemelen: this hypothesis attributes primary significance to the process of abyssal differentiation of terrestrial material in the development of our planet.

Taken together, these three hypotheses afford a complete explanation of the tectonic deformations of the earth, and of the distribution of tectonic activity both in time and space. The three hypotheses, however, have not been developed in conjunction, but rather independently of one another, despite the fact that variations in rotational velocity and pulsations of the figure of our planet are inevitably associated with pulsations of its volume, which, in their turn, bring about physico-chemical processes within the substance of the earth. For this reason a "combined" rotational-pulsational hypothesis,

based on the dialectic unity of pulsations of volume and shape of the terrestrial ellipsoid, and reflecting also the processes of abyssal differentiation within the earth, presents itself as most correct in the methodological sense, and most promising of results. Such a hypothesis, by its broad grasp /6
of the various tectonic processes, is superior to all others in this field (which are either one-sided as regards content, or are without physical or mathematical foundation), and in time may well develop into a more general tectonic theory--a theory of global deformations of terrestrial-type planets.

In the present volume are presented to the reader the origin and development of the earth's major forms of relief and the structures of its lithosphere--the continents, the oceans and the mountain belts--viewed from the position of the generalized hypothesis just described. At the present time such questions come within the purview of *planetary morphotectonics*, a new science comprising the sciences which deal with the earth and the universe at large. As in no other field of science, we are faced here with fundamental phenomena, which, clear and striking enough when presented on a map, remain enigmatical. To explain these phenomena is the purpose of this book.

I take this opportunity to express my gratitude to B. L. Lichkov and A. V. Khabakov, who were my first teachers in geology, and to L.P. Shubayev, Ya. Ya. Gakkel', V. Ye. Khain, and I. M. Zabelin, for their great help in preparing this volume for publication.

Leningrad, May 1953 - July 1960.

CUT ALONG THIS LINE

FOLD LINE

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
WASHINGTON, D.C. 20546

OFFICIAL BUSINESS

POSTAGE AND FEES PAID
NATIONAL AERONAUTICS & SPACE ADMINISTRATION

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
CODE USS-T
WASHINGTON, D.C. 20546

NASA TTF No.
533

FOLD LINE

CUT ALONG THIS LINE

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

TECHNICAL TRANSLATION EVALUATION

Budget Bureau No. 104-R037
Approval Expires: Sept. 30, 1969

TO:
THE USERS OF THIS TRANSLATION →

NASA TTF NO. 533

MAINTAINING THE QUALITY OF NASA TRANSLATIONS REQUIRES A CONTINUOUS EVALUATION PROGRAM. PLEASE COMPLETE AND MAIL THIS FORM TO AID IN THE EVALUATION OF THE USEFULNESS AND QUALITY OF THE TRANSLATING SERVICE.

THIS PUBLICATION *(Check one or more)*

- [ ] FURNISHED VALUABLE NEW DATA OR A NEW APPROACH TO RESEARCH.
- [ ] VERIFIED INFORMATION AVAILABLE FROM OTHER SOURCES.
- [ ] FURNISHED INTERESTING BACKGROUND INFORMATION.
- [ ] OTHER *(Explain)*: ______

FOLD LINE **FOLD LINE**

TRANSLATION TEXT *(Check one)*

- [ ] IS TECHNICALLY ACCURATE.
- [ ] IS SUFFICIENTLY ACCURATE FOR OUR PURPOSE.
- [ ] IS SATISFACTORY, BUT CONTAINS MINOR ERRORS.
- [ ] IS UNSATISFACTORY BECAUSE OF *(Check one or more)*:
  - [ ] POOR TERMINOLOGY.
  - [ ] NUMERICAL INACCURACIES.
  - [ ] INCOMPLETE TRANSLATION.
  - [ ] ILLEGIBLE SYMBOLS, TABULATIONS, OR CURVES.
  - [ ] OTHER *(Explain)*: ______

FOLD LINE **FOLD LINE**

REMARKS

FROM

DATE

NOTE: REMOVE THIS SHEET FROM THE PUBLICATION, FOLD AS INDICATED, STAPLE OR TAPE, AND MAIL. NO POSTAGE NECESSARY.

NASA Form 1332 AUG 66

GPO 915-777

CUT ALONG THIS LINE

CUT ALONG THIS LINE

THE MAJOR THEORETICAL PREMISES OF PLANETARY GEOMORPHOLOGY AND GEOTECTONICS

CHAPTER 1

THE FIGURE, ROTATION AND STRUCTURE OF THE EARTH

> ...Of necessity, we begin by describing briefly...the topmost layer, which is the cover of all the others--in other words, the surface of the earth itself. For this surface is really a part of the underlying portions, from which it borrows much by its very contiguity, and with which it interacts.. /7
>
> In studying this topmost layer, the first thing we must do is to consider the terrestrial figure, and after that the properties and qualities of the interior...
>
> --M. V. Lomonosov

Investigation of the figure of the earth, which in the past has been of enormous intellectual significance and greatly advanced the discovery of the great laws of nature, retains its general scientific value even today. During the past few years, particularly in connection with new planetary-physiographic, geotectonic, and planetological ideas, this problem has become still more pressing.

The first suggestion that the earth is spherical evidently came from Pythagoras (571 - 497 B.C.), who also originated the notion of the earth's daily rotation and its annual revolution around the sun. However, the first physical demonstrations of the earth's sphericity were adduced not by the Pythagoreans but by Aristotle (384 - 322 B.C.), in his *On the Heavens*, where he also suggests the smallness of our planet as compared with other celestial bodies. The proofs of these ideas are of course well known today. It was Archimedes (287 - 212 B.C.) who introduced into science the concept of the *spheroid*--a surface approximating the sphere. Archimedes' contemporaries and their successors in the ancient era had ideas about the shape and dimensions /8 of the earth which were fairly close to reality. This is attested by the result of the first known attempt to estimate the radius of the earth: the Alexandrian librarian Eratosthenes (276 - 194 B.C.), by estimating the latitudinal difference between Alexandria and Syene (the modern Aswan) on the basis of the known distance between the two cities, was able to arrive at a figure of 6,311 kilometers for the earth's radius. In view of the great primitiveness of the techniques available to Eratosthenes, one can say that the efforts of later Arab astronomers, who in 827 A. D. obtained a value of 6,406 kilometers on the basis of a measurement of the celebrated "arc of al-Mamoun", or of the French mathematician Fernel (1525), scarcely represent any advance beyond the work done by this ancient Greek scientist. It was only more than 1,800 years after Erathosthenes that a significantly more accurate determination of the size of the earth became possible, with the development of the method of triangulation.

This new epoch began with the work of the Dutchman Willebrord van Snell, who in 1615 was the first to make a trigonometric determination of the arc of meridian between Bergen and Alkmar in Holland. Of enormous significance were the measurements made by Picard, in 1669 - 1670, of the arc between Amiens and Malvoisin. Picard calculated the radius of the earth to be 6,371,692 meters. This quite accurate figure made it possible for Newton to justify the law of universal gravitation, which he discovered in 1665. The essence of this law and of the new doctrine of the figure of the rotating planet were presented in 1687 by Newton in his classic work *Philosophia Naturalis Principia Mathematica*. As is well known, the sources of this new doctrine were the six "books" published by Copernicus in 1543 under the title *De Revolutionibus Orbium Coelestium*. In this collection the great Polish astronomer struck the first powerful blow against fanatical geocentrism and anthropocentrism by explaining the apparent motion of the celestial bodies as being due to the axial rotation of the earth and its annual movement around the sun.

Still other consequences arising from the axial rotation of a planet within a gravitational field are discussed by Newton in the third section of his book, where, in particular, he writes: "If our planet were deprived of /9
its diurnal rotation, then, as a consequence of the absolutely equal gravitation of its particles in every direction, the earth would be forced to assume the form of a sphere. Actually, as a result of the rotation, particles near the equator tend to pull away from the axis. Hence, if the substance of the earth were liquid, it would, in rising, increase the equatorial diameter, and, in falling, diminish the polar axis." [1] Newton pointed out that "if our earth were not rather higher near the equator than at the poles, the seas would sink at the poles and rise at the equator, inundating everything." For a long time Newton's notion that the earth must originally have been liquid in order to assume its ellipsoidal figure was quoted in support of the hypothesis of a primordial molten earth. But by the middle of the 19th Century this hypothesis had been discarded by William Thomson (Lord Kelvin) and his school. In Thomson's opinion, even the insignificant plasticity of solid bodies would be quite sufficient to account for the shortening of the

[1] Is. N'yuton. *Matematicheskiye Nachala Natural'noy Filosofii* (Mathematical Principles of Natural Philosophy), Book 3, Petrograd, 1916, p. 477. [The Russian version of Newton's *Philosophia Naturalis Principia Mathematica*].

earth's axis. Newton's surmise is today quite valueless. We now know that, in response to the action of continuing forces (such as gravity), solid bodies behave as if they were liquids, while liquid bodies, in response to the action /10
of brief forces, behave as if they were solids (Figure 1). The material of the earth, like tar or resin, exhibits the properties of both solids and liquids: to an influence applied for thousands or millions of years, it reacts like an extremely viscuous liquid; to one applied only a few thousand years, like an elastic solid.

Fig. 1. Brittle Fracture of a Jet of Liquid by a Blow From a Rod (Photograph by M. Kornfel'd).

In studying the problem of the figure of a planetary mass 11 of whose particles are under the influence of forces of mutual attraction, as well as centrifugal force, Newton concluded the following:

1) the shape of the planet will be that of an ellipsoid with a slight polar compression, provided the rotation is not very fast[1]; and 2) the magnitude of the polar compression of the spheroid will be proportional to the ratio of centrifugal force to the force of gravity at the equator--namely,

$$\alpha = \varkappa_1 \frac{\omega^2 a}{g_e}, \qquad (2)$$

which is equal to 1/288. Here the coefficient of proportionality κ_1 depends upon the distribution of densities within the planet. Proceeding on the assumption that the earth's mass is homogeneous, or what is the same thing that its density is the same at all points (in which case $\kappa_1 = 5/4$), Newton obtained a value of 1/230 for the polar compression of the spheroid. Formula (2) suggests that the figure of the planet depends upon its dimensions (a), distribution of densities (κ), and the velocity of axial rotation (ω). It is now clear that the study of the figure and dimensions of the earth represents not merely a geometrical, but even more a geophysical and geodynamical problem.

---

[1] *Polar compression* is defined as the ratio of the difference between the equatorial and polar radii to the equatorial radius:

$$\alpha = \frac{a - c}{a}. \qquad (1)$$

The Dutch physicist Christiaan Huygens, who, as is well known, did not accept the law of universal gravitation, in 1690 determined the earth's polar compression, proceeding on a contrary assumption--that particles are attracted toward the earth's center, but not toward one another. This was equivalent to concentrating the whole mass of the planet at its center, and for this extreme case of density distribution the value of κ_1 in Formula (2) /11 would be 1/2. This, in turn, would give a value of 1/576 for polar compression, so that the actual value of α for the earth would fall between two limits.

$$\text{(uniform distribution of densities)} \quad 1/230 \geqslant \alpha \geqslant 1/576 \quad \text{(mass concentrated at center)}$$

Today, on the basis of data obtained with artificial satellites, we know that the polar compression of the earth and the structural coefficient κ_1 are 1/298.2 and 0.966, respectively.

The discrepancy between Newton's and Huygens' figures for polar compression, obtained theoretically, was first explained by A. Clairaut in 1743, also on a theoretical basis. As was pointed out above, this discrepancy is due to the fact that Newton and Huygens adopted two different assumptions which correspond to extreme cases of possible density distribution within the planet.

The church opposed Newton's theory of the figure of the earth, since of course it was based on the proscribed works of Copernicus, Galileo and Kepler. A certain Eisenschmidt, in 1691, in order to offset Newton, published a book in which he advanced the idea that the earth is an ovoid whose longer axis runs between the poles; this book was widely supported by the clergy.

At the middle of the 19th century, owing to inconsistencies in figures obtained on the earth's dimensions and polar compression by angular measurements of various parts of the planet, doubt arose whether the true figure of the earth is an ellipsoid of rotation. The Russian geodecist F.F. Shubert (1859) expressed the novel idea that the equator might be elliptical (the notion of the triaxiality of the earth).

As a result of this triaxiality the pole of our planet describes a certain, so-called nutational ellipse around its mean position, the major axis of this ellipse being perpendicular to the major axis of the equator. If the earth were an exact ellipsoid of rotation rather than a triaxial ellipsoid, then the curve in question would be a circle rather than an ellipse. As a result of processing the data of international observations made on polar oscillations during the period 1892 - 1924, the Soviet astronomer A. Ya.Orlov in 1944 arrived at the important conclusion that the triaxiality of the earth /12 actually exists, and that the major equatorial axis of the terrestrial ellipsoid lies in the plane of meridian 12° east of Greenwich.

Soviet scientists currently accept F. N. Krasovskiy's ellipsoid, the elements of which are as follows (Izotov, 1950):

Mean equatorial radius $\bar{a}$ = 6,378,245 meters;

Mean polar compression α = 1/298.3;

Equatorial compression ε = 1/30,000[1]; and

Longitude of greatest meridian, λ_a = 15° east of Greenwich.

Underlying these elements are degree determinations conducted in the Asiatic part of the USSR, Europe and North America. Therefore, the elements of the Krasovskiy ellipsoid on the whole characterize the figure of the earth more accurately than the Bessel, Hayford or Clark ellipsoids, which are based on a smaller number of degree determinations, and which reflect a smaller portion of the earth's surface. The Bessel ellipsoid is now used in the German Democratic Republic and the Federal Republic of Germany; the Hayford in England, and the Clark in North America.

The agreement between the results obtained by A. Ya. Orlov through very precise observations of oscillations of the terrestrial pole, and by F. N. Krasovskiy and A. A. Izotov from geodetic measurements, is convincing evidence that the *ellipticity of the equator (triaxiality of the earth) is a real factor* which must be taken into account in planetary-geomorphological and tectonic formulations.

Geodecists for the most part have conducted their investigations in the Northern Hemisphere (Bessel, Hayford, Clark, Heiskanen, Krasovskiy, etc.), and have thus not described the figure of the earth as a whole, but only its northern half. In 1952 and 1956, I. D. Zhongolovich published the elements of a *general terrestrial ellipsoid* which were calculated with allowance for gravimetric measurements made in both the Northern and the Southern Hemispheres (See Appendix 1). It would appear from Zhongolovich's work that the /13 dimensions of the earth are smaller, and the polar compression greater, than was previously believed.

It has long been known that the Northern and Southern Hemispheres are nonsymmetrical. This nonsymmetry is reflected morphologically in the fact that in the Northern Hemisphere there is a predominance of continents, and

[1] Equatorial compression is defined as the difference between the major and minor equatorial semiaxes divided by the major equatorial semiaxis:

$$\varepsilon = \frac{a-b}{a}. \qquad (3)$$

in the Southern a predominance of oceans; that there is a southern polar continent, but not a northern one; that the northern zonal Appalachian-Alpine-Himalayan mountain belt is more pronounced than the antipodal latitudinal belt in the Southern Hemisphere; and so on. It can be said that the Northern and Southern Hemispheres are in fact *antisymmetrical:* one is the mirror-image of the other. If the map of one hemisphere is superimposed on that of the other, it will be found that every depression coincides with an elevated area, and vice versa. The geological history, structure and material composition of the earth's crust are different for the two hemispheres.

From this very important fact of the asymmetry of the two hemispheres, and the structural difference between them, it follows that the asymmetry of the earth with respect to the equatorial plane is necessarily associated with special forces creating the asymmetry of rotating bodies. However, classical (Newtonian) mechanics suggests nothing about the existence of any forces other than gravitational and centrifugal. Therefore, if we are to remain within the framework of Newtonian mechanics, we cannot understand, much less explain, why the Northern and the Southern Hemispheres of our planet are so different. It is also obvious that our theoretical concepts of the world around us, and of the figure of the earth in particular, would have been very different from the existing ones if we had been privileged to observe the forces which gave rise to the asymmetry in the figure and the structure of our planet's surface (N. A. Kozyrev, 1958, G. N. Katterfel'd, 1958)[1]. The north-south asymmetry of the earth is explained by the assumption that these forces are directed parallel to the axis of rotation, since the corresponding shift of the center of terrestrial masses toward the north from the equatorial plane would result in increased polar compression in the /14
Southern Hemisphere and decreased polar compression in the Northern Hemisphere. Therefore, the Southern Hemisphere would become more compressed than the Northern, and the terrestrial spheroid would assume a heart-shaped form--the cardioid--with an axial depression at the South Pole and a protuberance at the North Pole (Figure 2). From this, three important facts follow: a) the distribution of gravitational forces is necessarily different for the two hemispheres, b) the true mean compression of the earth must be somewhat less than 1/298.3, and c) the true dimensions of the earth must be somewhat different from those generally accepted at the present time.

The influence exercised by hemispherical asymmetry on the distribution of gravitational forces was first studied by the Russian astronomer A. A. Ivanov (1899), a professor at the University of Petersburg. Ivanov obtained a value of 1/297.2 for the mean compression of the spheroid.

Justification of the three conclusions cited above may be found in /15
results obtained by I. D. Zhongolovich, which include a polar gravity differential of 30 milligals, a mean polar compression of 1/296.6, and a terrestrial radius of 6,370,949 meters--208 meters less than the figure accepted earlier.

[1] The question of the nature of asymmetrical forces, despite a witty attempt to deal with them as forces of "the course of time" (N.A. Kozyrev, 1958) remains open.

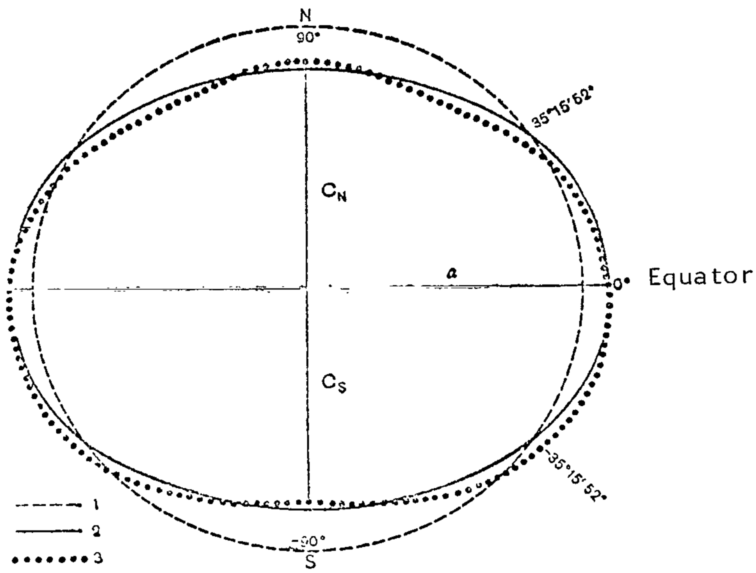


Figure 2. Comparison of a Sphere (1), Spheroid (2) and Cardioid (3).

It has recently become possible to refine our ideas of the figure of the earth on the basis of observations of the motion of artificial satellites launched in polar orbits. The asymmetry of the earth necessarily has an effect on the motion of these bodies: the smaller the mass of the satellite, the greater the distortion of its orbit. This is clear from Newton's second law, according to which bodies subjected to identical forces acquire accelerations inversely proportional to their masses. Observations made on the motions of artificial satellites have supplied the following figures for mean polar compression (α) and polar asymmetry of the earth η[1], $\alpha = 1/298.2$ (D. King-Khel' and R. Merson, 1959, and $\eta = 1 \cdot 10^{-5}$. Corresponding figures for the differences between the equatorial and mean polar semiaxes a - c and the polar semiaxes $C_N - C_S$ are as follows:

$$a - c = 21\,389 \text{ м}, \qquad C_N - C_S < 100 \text{ м}.$$

[1] Polar asymmetry is equal to the difference between the polar semiaxes divided by the equatorial diameter of the planet:

$$\eta = \frac{C_N - C_S}{2a} \tag{4}$$

or, what is the same thing, the half-difference of the polar compressions of the Northern and Southern Hemispheres:

$$\eta = \frac{\alpha_S - \alpha_N}{2}. \tag{4a}$$

Consequently, in view of the insignificance of the deviations of the earth's figure from the ellipsoid (in the direction of cardioidal shape), it would be more appropriate to use the term *cardioidal ellipsoid* rather than *cardioid.*

Now let us examine the forces acting upon the earth, and the deformations which they produce in sequence of time, proceeding from the simplest forms to the more complex.

In the absence of rotation and other disturbing external forces, the figure of the planet would be determined entirely by gravitational forces and would therefore be a *sphere.* /16

Under the influence of centrifugal forces of rotation, the figure of the earth would be an ellipsoid of rotation--a *spheroid* (See Figure 2). However, in addition to centrifugal forces, asymmetrical forces of rotation also act upon the planet, as a result of which the figure of the earth has assumed the more complicated shape of a *cardioidal ellipsoid.*

Thus, the primary sphere, contracting under the effect of gravity, and being deformed by centrifugal and asymmetrical forces of rotation, acquires the shape of a cardioidal ellipsoid. Whereas the spheroid is a sphere deformed by centrifugal forces, the cardiodal ellipsoid is a spheroid deformed by asymmetrical forces of rotation.

Thus, the figure of the earth and of other planets is determined (1) by gravitational forces in combination with centrifugal forces of rotation, resulting in flattening of the sphere and in the formation of an ellipsoid of rotation, and (2) by asymmetrical forces of rotation, which tend to transform the terrestrial spheroid into a cardioidal ellipsoid.

Gravity, to be sure, consists of more than mere attraction toward the center of the planet, for one must consider the gravitational action of other bodies in the universe--the moon, the sun, and the other planets. As a result of such action the figure of the earth shifts in its equatorial cross-section, assuming the form of an asymmetrical-triaxial ellipsoid.

Tidal forces not only act on the more mobile *envelope* of the earth (the atmosphere and the hydrosphere), but--what is particularly significant--also deform the solid portion of the planet. The meridional asymmetry of the earth's figure is greater in proportion as the external body causing the tides is nearer to the planet.

Thus, the difference which today we observe in the height of lunar tides in the earth's crust amounts to 5 percent (for opposite hemispheres). In the distant past, however, when the moon was a good deal closer to the earth, the difference was dozens of times greater.

Analysis of seismic data has shown that our earth consists of three basic portions--the lithosphere (crust), the mantle (envelope), and the core. Usually, the boundaries between these portions are represented in the form of perfectly spherical surfaces, as is the external surface of the earth. The unevenness of the surface (relief of the geosphere) is very small in comparison with the dimensions of the planet; for purposes of illustration, a great exaggeration of the vertical scale is necessary.

The surface separating the lithosphere and the mantel is the so-called Mohorovivic discontinuity. This surface lies an average 35 kilometers below the continents, and 10.5 kilometers below the oceans, counting from the surface of the hydrosphere--that is to say, 4 or 5 kilometers below the ocean floor (Figure 3). The boundary of the earth's core lies at a depth of 2,900 kilometers--that is, at a distance equal to 54% of the earth's radius (0.54 R). It is a point of interest that the area of the surface of the core (as computed with high accuracy, amounting to one-tenth of one percent) amounts to 148,700,000 square kilometers, thus very nearly coincid- /18 ing with the area of the surface of the continents--148,900,000 square kilometers[1]. Within the core is a "little core", located at a depth of 5,090 kilometers; this "core of the core" has a radius of 20% of the earth's radius (0.20 R).

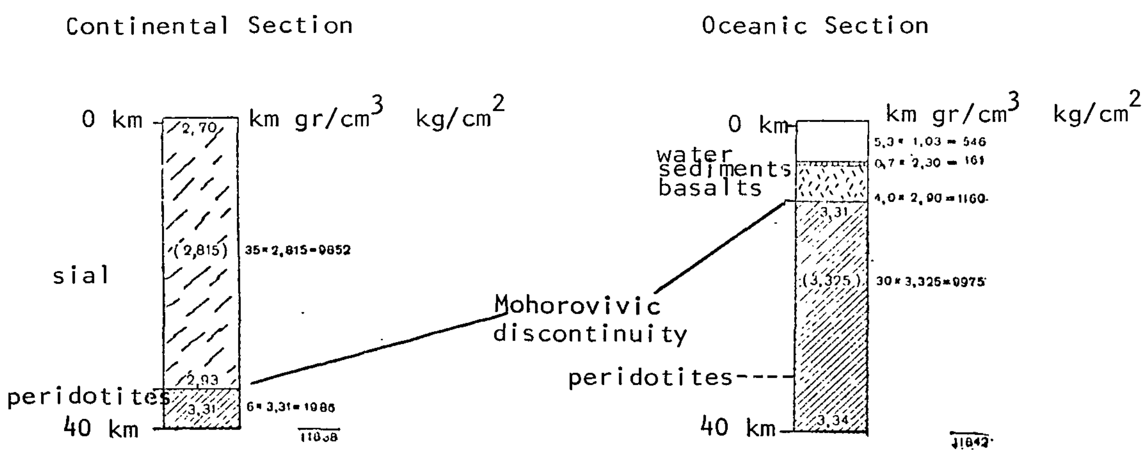


Fig. 3. Content of the Continents and Oceans (On the Basis of Seismic Data and the Conclusions of Petrology; Gravitational Equilibrium is Assumed).

(After H. Hess, 1955)

---

[1] This can scarcely be accidental. Evidently the formation and growth of the sialic lithosphere was somehow associated with the formation and possible increase of the core during the course of geological history.

The lithosphere, or "earth's crust", consists of three layers: a thin layer of sedimentary rock, a granitic layer and a basaltic layer.

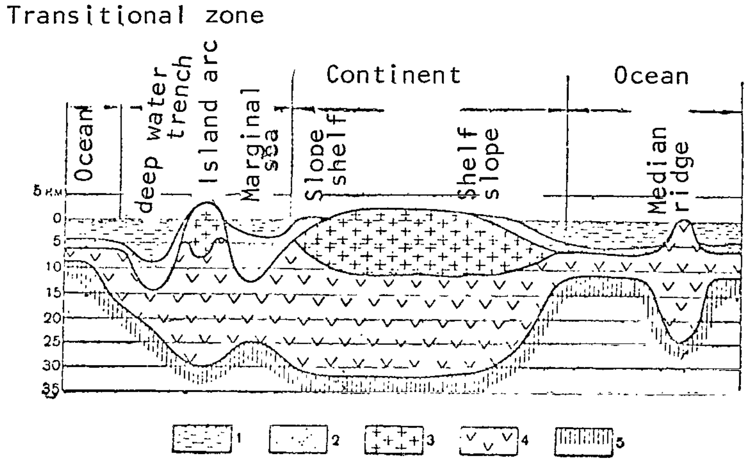


Fig. 4. Generalized Schematic Representation of the Earth's Crust (After V. Ye. Khain, 1961). 1, water, 2, sedimentary layer; 3, granitic layer; 4, basaltic layer; 5, mantle.

The granitic layer fades out on the floor of the oceans. The basalts begin under a thin cover of uncompacted and semicompacted sediments less than 1 kilometer in thickness. The mean thickness of the basaltic layer is 4 kilometers, but it is much thinner than this in the deepest parts of the ocean. The fading out of the earth's crust in the horizontal direction away from the continents is illustrated in Figures 4 and 5. In Figure 5 is shown the gradual attentuation of the lithosphere in the region of transition from continent to ocean at Cape May on the Atlantic coast of North America. A similar situation is observed on the Atlantic coast of Europe. /19

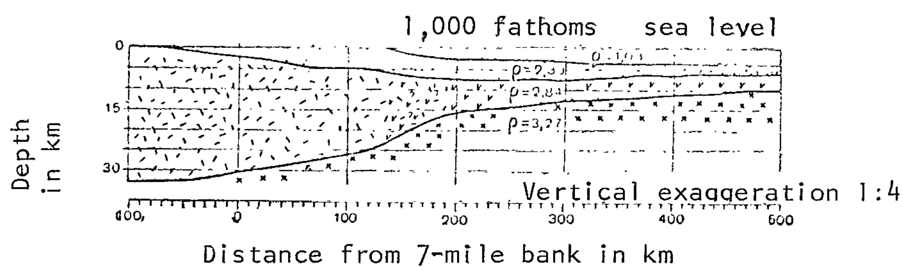


Fig. 5. Section of the Lithosphere at Point of Transition Between the North American Continent and the Atlantic Ocean (After Werzel and Sherbet, 1955).

The layers in the order of increasing density are: sea water, sediments, lithosphere, mantle.

There are other means of "articulation" between land and sea, particularly thrust surfaces and fault surfaces. We find this in the case of the Pacific coast of Southeast Asia, the California coast, and many other regions. It has been established that in all cases where the lithosphere is free from marine or oceanic waters over extensive areas, or is covered by not more than 1,820 meters of water, it is of continental type, and where the water cover is 3,640 meters or more, it is of oceanic type (Ewing and Press, 1955). In the interval between these two depths (1,820 and 3,640 meters below sea level), one finds a lithospheric structure which is intermediate between continental and oceanic. The lithosphere underneath the Mediterranean and the Caribbean is oceanic rather than continental.

The density of the upper layers of the lithosphere is 2.70 gr/cm^3, as against a general mean of 2.82 gr/cm^3. The underlying mantle has a density of 3.31 gr/cm^3 in its upper portion, but a density of 5.68 gr/cm^3 in its core; at the center of the earth the density evidently reaches 17 gr/cm^3.

All igneous rocks that we are familiar with fall into one of the following four categories: acid, intermediate, basic and ultrabasic (Table 1). /20

TABLE 1. Chemical Composition of Certain Characteristic Widely-Distributed Terrestrial Rocks (in %)[1]

Composition	Acid	Intermediate		Basic	Ultrabasic	
	Granites	Andesites	Diorites	Basalts	Dunite	Amphibolic Peridotite
Silica, SiO_2	70.18	59.59	58.90	49.06	40.49	40.91
Alumina, Al_2O_3	14.47	17.31	16.47	15.70	0.86	5.00
Magnesium oxide, MgO	0.89	2.75	3.57	6.17	46.32	30.82
Ferric oxide, Fe_2O_3	1.57	3.33	2.89	3.58	2.84	4.64
Ferrous oxide FeO	1.78	3.13	4.04	6.37	5.54	7.97
Calcium oxide, CaO	1.99	5.80	6.14	8.95	0.70	4.41
Other compounds	9.12	8.09	7.99	10.17	3.25	6.25

[1] From data in V. A. Magnitskiy's book (1953).

The rocks of the lithosphere, which is the earth's outer stony envelope, are rich in silica (SiO_2) and aluminum compounds. It is precisely this combination of sedimentary, granitic and basic rocks which gave rise to the widely used term *sial* (Si + Al) introduced by E. Suess (1909, p. 626). The granitic and basaltic rocks, along with the products of their decomposition are concentrated in the sedimentary mantle, forming the earth's lithosphere above the Mohorovivic discontinuity. As regards the ultrabasic rocks, which are comparatively poor in aluminum but rich in magnesium (Suess' term is *sima*, from Si + Mg), they appear under the lithosphere directly below the Mohorovivic discontinuity, and probably extend down to a depth of 2,900 kilometers.

The earlier hypothesis of the ferrous nature of the earth's core, which still figures in some textbooks, can no longer be accepted in the face of serious geophysical and cosmogonic arguments to the contrary. According to the works of V. N. Lodochnikov (1939) and V. Ramsey (1948, 1949), the formation of the earth's core is to be explained by a phasal transition of silicate material into the metallic state[1], as a result of the high pressure in the earth's interior. According to Lodochnikov's hypothesis, the great /21 density of the earth's core is explained not by its iron content, but rather by the enormous magnitude of the pressure. Nevertheless, we are in no position to assert that the chemical content of the mantle and that of the core are the same. It is more probable that there is a certain difference, possibly small, between them. With a pressure of 1,400,000 atmospheres at the boundary of the core, the planetary substance would enter the metallic phase in stepwise fashion. This phenomenon is caused by the "crushing" and disruption of the electron shells, and by the corresponding diminution of the oxygen atoms which constitute the greater part of the planetary substance.

The smooth increase in density in connection with high pressure, and the presence of a phase transition, enable us to understand the formerly mysterious linear relationship existing between the density of the terrestrial planets and their dimensions or mass. Actually, since a dense core of a planet is determined only by the region close to the center of the planet, where the pressure exceeds the critical (for phase transition) value of 1,400,000 atmospheres, a planet with small mass and comparatively small pressure at the center could not possibly have such a core. Calculations show that of all the terrestrial planets, we find such a critical value of pressure only in the case of Venus and the earth; the moon, Mercury and Mars have lower pressures at their centers (S.V. Kozlovskaya, 1953). Only Venus has a dense core such as our own (but smaller)[2].

---

[1] A weak link between electrons and the atomic nucleus, and also high electrical conductivity, are characteristic of this condition.

[2] As is well known, it is currently believed that the phenomenon of terrestrial magnetism is associated with the presence of a liquid metallic core within the earth. That the moon is without any magnetic field (as was established recently by direct measurements made with the help of Soviet lunar rockets) supports the hypothesis of the absence of a lunar core. We may expect that Mars, lacking a dense core, will similarly be without a perceptible magnetic field.

Neither the moon nor Mars, and apparently also Mercury, has a sialic crust of terrestrial type.

It should be noted that the widely used and traditional expression *earth's crust* (a synonym for *lithosphere*) no longer suggests the meaning it is meant to convey; it is a relic from the comparatively recent epoch in which a belief in the primarily igneous-liquid state of the earth's substance /22
was predominant. The "earth's crust" was regarded as a shell of slag floating on the surface of the planet. The congealing of this layer was the culmination of the "igneous-liquid" stage of development of the earth. But according to the modern theory of the gas-dust origin of the earth, the lithosphere is by no means a slag crust rapidly solidified on the surface of an igneous-liquid planet, but rather the product of a prolonged process of physico-chemical and gravitational differentiation of the substance of the mantle. This disparity between the old and the new point of view corresponds to a substantial difference in estimates of the age of the earth's crust. From the point of view of the "hot" cosmogonies, the formation of the crust was so brief as to be practically coeval with the formation of the earth itself. But modern data on the "cold" formation of the earth and the long-term formation of the lithosphere (it is probably continuing even at the present time), indicate that there is absolutely no comparison between the age of the earth and the age of the earth's crust. In fact the very concept of the age of the lithosphere has become suspect, since layers and fragments of the most diverse ages, from the very ancient to the very young, have entered into the composition of what we call the earth's crust.

The total volume of the lithosphere is estimated to be 1.2% that of the earth itself, or 1.5% that of the simatic shell. The mass of the lithosphere is 0.7% that of the earth, or 1% that of the shell (P. N. Kropotkin, 1953). The remaining 99% is made up of ultrabasic (and metallic) material, which today is regarded as the primary material from which, in the course of prolonged differentiation, a more acid lithosphere (that is to say, its basaltic and granitic layers) has been formed. The sedimentary layer,in turn, is the product of the destruction of those layers; it has accumulated as a result of steady deposition and redisposition within the basins of the earth's surface.

Since the lithosphere is the product of the differentiation of the shell, the earth's mantle lying beneath the continents and oceans must have a somewhat different density. But in view of the small mass of more acidic differentiate given off by the shell, the difference (approximately 0.03 /23
gr/cm^3) is barely perceptible. The formation of the lithosphere has exerted an equally small influence on the distribution of densities along the earth's radius.

The former popular "hot" cosmogonies of Laplace (1796) and Jeans (1919), and also the later hypothesis of V. G. Fesenkov (1944) that the planets were formed from incandescent patches of solar gas, have now been universally discarded. Therefore, the geochemists' ideas of a primordial molten earth, the foliation of the planet into geospheres, and the existence of a primary molten magma--all of which derive from the earlier cosmogonies referred to above--have proven unsound.

Moreover, the scientific literature is deeply permeated with the mistaken notion that the foliation of the earth with respect to chemical content logically follows from the hypothesis of the earth's primordial igneous-liquid state. Actually, as B. Yu. Levin (1955) has pointed out, this opinion is based on erroneous analogies in which the earth is likened to a blast furnace or a meteorite, without proper account being taken of the planetary scale of events. At pressures deep in the interior of the earth which reach several million atmospheres, the viscosity of the terrestrial material is so great (for any temperature one cares to assume) that it is no longer meaningful to speak of the "liquid" state. Therefore, no matter how much heating occurs in these depths, and no matter whether the heat is "primordial" (as in the "hot" cosmogonies); the result of radiation (as in O. Yu. Schmidt's theory, 1950); or is generated by the braking of the earth's rotation by tidal action (the hypothesis of P. P. Zotov; 1960), the very idea of the geochemical differentiation of the substance of our planet in the liquid state is erroneous.

Seismic investigations have yielded important demonstrations that the entire mantle of the earth, down to the core, is in a solid state. Nevertheless, even in such a solid state (more precisely, the state of an extremely viscuous shell), there exist conditions for the rise of silicate fusions, without which the formation of the sialic lithosphere and the continents would have been impossible. As a consequence of the formation of deep fis- /24
sures and the reduction of pressure in certain regions and belts of our planet (we shall return to this subject in the following chapter), it was possible for individual, isolated cavities to arise in the mantle, which were filled with comparatively light and readily fusible basaltic and granitic magmas saturated with volitile substances similar in composition to eutectics[1]. Such granitic (quartz + aluminum silicates) and basaltic (pyroxene + plagioclase) eutectics, by virtue of their low melting points, plasticity and lower (by comparison with the dunite-peridotite rocks of the mantle) specific gravity, could be readily transported upward along fissures, thus paving the way for the sialitic lithosphere and supplying material for the formation of continents and mountains.

Thus, the basic differentiation of the planetary substance into core, mantle and lithosphere, was by no means the original one. It could not have arisen as a consequence of some secondary, radiogenic heating of the depths. The foliation of the earth can be regarded as the result of quite prolonged processes of gravitational compression and condensation of the interior layers of the planet (the formation of a core), and of the physico-chemical and gravitational differentiation of the substance of its shell (formation of the lithosphere). These processes are continuing even today. There can be little doubt that the present-day macrostructure reflects only a

[1] A eutectic is such a mixture of two or more compounds as has the lowest melting point for all possible mixtures of the particular components.

particular stage in the development of the planet.

With increase in the concentration of matter toward the center of the planet, the flattening of the poles diminished. Therefore, increase in the internal homogeneity of the earth in the course of time leads to a general and consistent alteration of the planet's figure showing itself in a secular diminution of polar compression.

The progress made by the planet during its course of development is circumscribed by its mass (and dimensions). The mass of the earth was sufficient for the formation of a dense, internal core. However, as long as the mass of the growing planet remained below 0.8 of its present value, no core appeared: that happened only at a critical epoch in the early history /25
of the earth, when the mass reached 80% of its present value. This event and the subsequent contraction of the earth's radius (by approximately 100 kilometers) produced a sharp increase in the rate of axial rotation.

Mars, with its insufficiently large mass, was unable to form a dense core, and therefore has lagged behind the earth in development. It differs from our planet in its smaller mean density, and in having less mass concentrated toward the center. This explains the smaller polar compression of Mars, although the diurnal rotation of the two planets is the same.

CHAPTER 2

THE CAUSES OF TECTONIC MOVEMENTS

> Geologists, in observing actual geological processes, so limited by the volume of the earth itself, very often forget that their basic features (including the physico-chemical ones) are determined primarily by the figure of the planet as a celestial body--a triaxial ellipsoid, a geoid close to the ellipsoid of rotation--as a unique whole, on the basis of its geometry.
>
> --V. I. Vernadskiy

Tectonic movements, which create, alter, and continuously renew the face /26
of our planet, have a wider sphere of action than the lithosphere, which is only the thin, stony film on the surface of the globe. These movements affect not merely the external layers, but virtually the whole of the earth's mantle. Some tectonists (V. Ye. Khain, 1957, *et al*) justifiably believe that even the earth's core is by no means free of these all-planetary movements, which, essentially, have given our world its very countenance. But the course and character of abyssal tectonic processes are not independent; rather, they are *intimately related to the cosmic conditions of the earth,* to the earth's irregular axial rotation and the orbital motion of its satellite, the moon.

Variations in Rotational Velocity

Everything that once was firm and constant, with the advance of practical human requirements and improvement in the accuracy of scientific measurements (that is to say, with more attentive and careful examination) has become variable and unsure. The ancients could afford to consider the earth immobile; /27
then in 1543 Copernicus ushered in a new epoch with his discovery that the earth goes round the sun--at the enormous velocity of 30 kilometers a second. Still later it was observed that our planet is not the good clock it was supposed to be, for sometimes it spins faster, sometimes slower. Johannes Kepler discovered that planetary orbits are ellipses, and showed the variability of the earth's velocity around the sun.

With a freely rotating body left to itself, the moment of momentum (that is, the product of the rotational velocity ω and the moment of inertia I) remains constant.

For the earth the moment of inertia is $I = 0.331MR^2 (1 + 2/3\alpha)$, where 0.331 is a structural coefficient depending upon the distribution of densities within the planet, M is the mass, and R is the mean radius. Consequently, if the moment of inertia diminishes (for example, as a result of reduction of the structural coefficient or the mean radius of the earth), then the rotational velocity will increase. With increase in the volume of the earth, the mean radius and the moment inertia will also increase, but the rotational velocity will diminish.

All this is natural under conditions of free rotation. However, the earth comes under the influence of external forces, and as a result its axial rotation is impeded. In 1754 Immanuel Kant in his remarkable "Investigations of the Question of Whether the Earth has Experienced...Certain Changes in Axial Rotation", called attention to the fact that the friction of a tidal wave opposing the rotation of the earth and acting incessantly on the eastern shores of the continents, would necessarily diminish the earth's rotational velocity. In 1848, Julius Robert Meyer, one of the founders of the law of the conservation of energy[1], pointed out that the effect of lunar and solar gravitation upon the earth shows itself not only in precession and nutation /28
but also in variability in the planet's rotational velocity--in other words, the position of the axes of rotation actually shifts in space and the rotational velocity is altered. Like Kant, Meyer insisted that the tides of the Pacific diminish the rotational energy of the earth.

After the work of Meyer, this question aroused strong interest among geophysicists and astronomers. John C. Adams (1859)[2], G. H. Darwin (1879, 1908), and S. Oppenheim (1886), among others, occupied themselves in finding the magnitude of tidal retardation. Even during our time (in the 1930's), Brown established the existence of jump-type variations in rotational velocity, taking place at intervals of 0.5 - 2 and 10 - 60 years. These jumps are associated with variations in the earth's moment of inertia. As a result of the shifting of masses within the body of the earth from the center and from the axis of rotation, there is a retardation of rotational velocity; when the shifts take place toward the axis and toward the center, there is an acceleration of the velocity of rotation.

Apart from secular retardation and jump-type changes, the earth's rotational velocity, as shown with the use of quartz clocks, also undergoes annual variations. It has been shown that the March day is 0.0025 seconds longer than the August day, and that, consequently, the earth's rotation speeds up toward August and slows down toward March. This phenomenon is explainable in part through the seasonal change in the atmosphere (N. N. Pariyskiy, 1955), in part through variation in the "temperature" of the earth as a whole, associated with annual variation in the earth-sun distance.

---

[1] See Meyer's article, "Observations of the Forces of Inanimate Nature", in the May booklet of the Liebig *Annals of Chemistry and Pharmacy* (in German) for 1942; also his original outline, *Celestial Mechanics*, published in 1848.

[2] See Thomson and Tait, 1883.

It is possible that on the "farther" sector of the path around the film (between March and September), the earth is slightly cooled in comparison with the "nearer" sector (between September and March). Calculations show that even with sharply decreased mean coefficient of thermal expansion of the earth, the order of 10^{-8}, a decrease in the mean temperature of the entire earth from March to September of only 1.4° would be sufficient to cause a decrease in its mean radius of 9.2 cm. This change in radius of the earth between March and September, according to the law of conservation of rotational inertia:

$$L = \varkappa M R^2 \omega \left(1 + \frac{2}{3} \alpha \right) = \text{const} \tag{5}$$

(where R is the mean radius of the planet, ω is the angular velocity of its rotation), should cause exactly the seasonal increase in rotation rate during the period between March and September which is actually observed for the earth. The supposed annual change in the radius of our planet should be accompanied by certain other effects, particularly annual fluctuations in the level of the world ocean. Increases in the level between September and March are actually observed, amounting to around +10 cm.

The rotation of the earth, in addition to secular retardation, also experiences secular acceleration, caused by gravitational compression and condensation of its interior portions. For this reason, the observed secular retardation ($\Delta\omega/\omega = -2.8 \cdot 10^{-8}$) is compounded of the true secular retardation resulting from tidal friction ($\Delta\omega_e/\omega = -4.2 \cdot 10^{-8}$), and the proper secular accleration, resulting from gravitational compression and the shortening of the planet's radius ($\Delta\omega_i/\omega = +1.4 \cdot 10^{-8}$). Here, the secular retardation is three times as great as the secular acceleration--that is, the effect of external factors (the attraction the sun and moon, tidal friction of the atmosphere and hydrosphere, etc.) is greater than the effect of internal factors (gravity). /29

Thus, the observed variations in the earth's rotational velocity consist of four separate components: 1) secular, continuous retardation as a result of external tidal braking; 2) proper acceleration as a result of uneven contraction of the radius of the external geospheres; 3) jump-type variations of periodic character; and 4) periodic variations associated, in particular, with the time of year (the earth's position with respect to the sun).

All of these varied influences, admittedly small or even insignificant, have nevertheless left their mark on our planet, in my opinion. If we were able to sum up and analyze all those minute, but innumerable, pulsational and rotational effects which have accumulated during the four billion years of geological history and have subtly made themselves felt on the countenance of our planet in the form of continuing, though possibly impalpable interactions, then we should be amazed at their overall significance.

Pulsation of the Volume of the Earth /30

As B. Meyermann (1928, 1928a) and N. N. Pariyskiy (1955) discovered, the mean rate of contraction of the earth's radius, as a result of abyssal compression during the modern epoch, amounts to 5 centimeters a century. The substance of the planet is subjected to the greatest deformation at depths on the order of 2,700 kilometers, where a pressure of 1.2 million atmospheres predominates. Here, there is a significant increase in density and reduction in the volume of the planetary substance associated with denser packing (A. P. Vinogradov, 1959). This contraction of the terrestrial radius liberates an enormous amount of energy; approximate calculations yield a figure of $17 \cdot 10^{30}$ ergs per century, which in thermal units is equivalent to $4 \cdot 10^{23}$ calories. Even a moderate shift in the internal structure of the earth as a result of compression and gravitational differentiation, or a comparatively small increase in the mean terrestrial density, will lead inevitably to the release of quite significant amounts of thermal energy. Since only a portion of that energy is dissipated within "terrestrial space", the planet becomes heated, and the stage of compression is followed (but only for a time!) by a stage of expansion. Consequently, gravitational compression is the precursor, and indeed the cause, of a subsequent stage of expansion--a stage in which the forces of repulsion predominate over the forces of attraction.

Thus, the contraction of the earth's radius is not uniform; it is a discontinuous process in the form of a pulsation. In individual years (for example, 1897) such variation in the mean terrestrial radius has reached 12 centimeters. There is a single circumstance which greatly intensifies the oscillations and the unstable character of radial contraction. As follows from the formulas adduced in P. N. Tverskiy's *Course in Geophysics* (1936), the pressure at the center of the planet P_c, in first approximation, is inversely proportional to the fourth power of the earth's radius R:

$$P_c = \frac{3fM^2}{8\pi R^4}, \qquad (6)$$

where f is the gravitational constant and M is the mass of the earth.

According to this expression, reduction in R is accompanied by a sharp increase in pressure in all layers of the planet, while the core is enriched by new masses of substance drawn from the deeper portions of the mantle, thus /31 undergoing still further compaction and increase in size. Conversely, with increase in R, there is reduction of the pressure, and this in turn favors additional increase. Such instability in the mechanical and physico-chemical state of the internal portions of the earth leads to oscillation in the terrestrial radius R, superimposed against a background of general secular contraction of the radius. This discontinuous-continuous character of the radial contraction is explained by the incomplete reversibility of the process itself, resulting from the transfer of a portion of the gravitational potential energy into the latent heat of physico-chemical transformations.

Thus, the basic source of energy of tectonic movements, and of the deformations in the mantel and lithosphere associated with them, is gravity. Gravitational contraction of the terrestrial radius is accompanied by acceleration of the rotation of the planet(and this is opposed by tidal retardation); here an enormous amount of energy is released, which, ultimately, goes into (1) heat lost by the earth through radiation into space, or (2) the latent heat of physico-chemical transformations deep within the earth, which proceed upon reduction of the volume of planetary substance, and which in their turn promote still further compaction of the interior portions of the planet and reduction in planetary volume. Radiogenic heat produced within the earth is less important than the heat of tectonic origin, since it is owing to tectonic movements that the shifts of radioactive elements occur, whereas the release of energy in connection with gravitational shift of the terrestrial radius exceeds by a factor of 100 the release of heat through radioactivity.

Variation in the Figure of the Earth

The ellipsoidal figure of the earth is characterized by a degree of polar compression which can be expressed by the equation

$$\alpha = \varkappa_1 \frac{\omega^2 a^3}{fM}, \qquad (7)$$

where f is the gravitational constant, ω is the rotational velocity, a is the equatorial radius, M is the mass, and κ is the structural coefficient reflecting the distribution of densities within the planet. This expression shows that the magnitude of polar compression depends upon the internal structure, the rotational velocity, the dimensions, and the mass of the planet. Changes in the ellipsoidal form of the earth resulting from external and internal causes as well as from factors in the history of the planet are represented by the following relationship: /32

$$\frac{1+\alpha}{1+\frac{2}{3}\alpha}\,\frac{\Delta\alpha}{\alpha} = \frac{2\Delta\omega}{\omega} - \left(\frac{2\Delta\varkappa}{\varkappa} - \frac{\Delta\varkappa_1}{\varkappa_1}\right) - \frac{\Delta R}{R} - \frac{3\Delta M}{M}. \qquad (8)$$

variation in form (polar compression)	=	variation in ω, associated with external causes	+	variation in internal structure	+	variation in dimension	+	variation in mass of planet

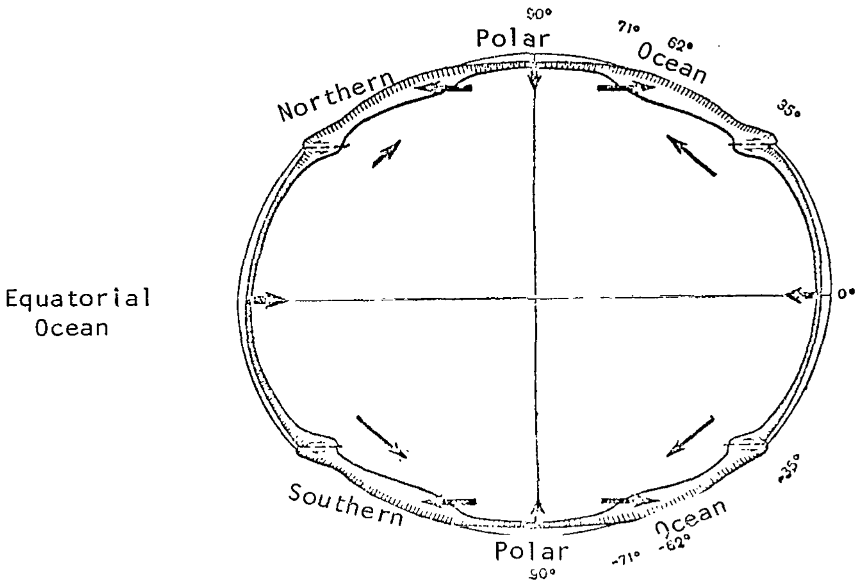


Fig. 6. Deforming Forces and Zonal Plan of the Planet With Identical Secular Reduction of Polar Compression of Northern and Southern Hemispheres.

In connection with the fact that the numerical magnitudes of the factors introduced here are of different signs, their combined effect is less than would be indicated by a simple sum.

For example, Jeffries in 1929, assuming the dimensions of the earth and the distribution of densities within the planet to be invariable, calculated that 1.6 billion years ago the polar compression of the earth amounted to 1/210. But allowance for the possible variation in dimensions and internal structure greatly reduces this estimate. A precise value for total variation in polar compression for the whole period of geological history, with due allowance for all these factors, would be difficult to arrive at at the present time--possibly even impossible. Nevertheless, from Expression (8) we can arrive at an answer to a question which is of importance in understanding the basic tendencies at work in shaping the face of the earth: what has been the general direction followed by changes in the form of our planet? Calculations show that in the course of time, as a result of the great influence of tidal retardation, polar compression of the terrestrial spheroid has been falling off. On this slow secular reduction of the earth's flattening are imposed pulsational oscillations associated with the instability of the mechanical and physico-chemical equilibrium of the planet. /33

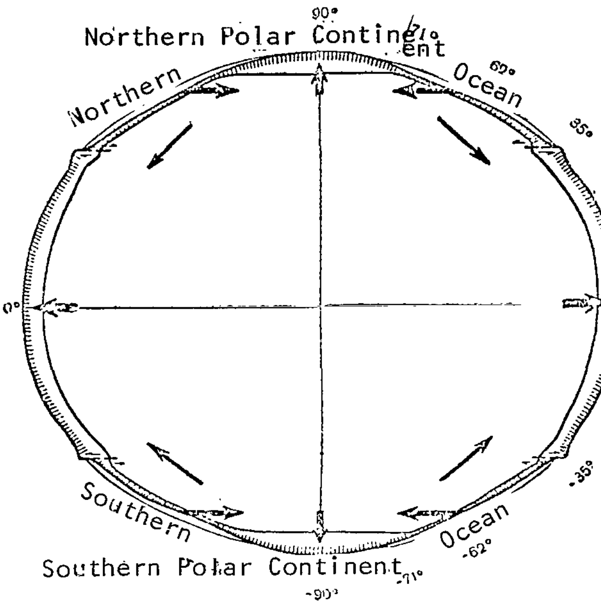


Fig. 7. Deforming Forces and Zonal Plan of the Planet with Identical Secular Increase in Polar Compression of the Northern and Southern Hemispheres.

The distribution of tectonic stresses within the lithosphere and of movements within the subcrustal sphere of the earth during rotation-induced change in polar compression, has been studied by Böhm von Böhmersheim (1910), H. Quiring (1921), V. A. Magnitskiy (1948), and M. V. Stovas (1951, 1957, 1958, 1959)[1]. /35

A sinking in the equatorial bulge, and a rise in the polar regions, are the necessary consequences of any prolonged reduction in polar compression. Then, under conditions of downward movements of the planetary substance and increased pressure, the equatorial zone would become a region suitable for the formation of the oceanic type of lithosphere, while the temperate zones, experiencing upward movements and reduced pressure, would support a lithosphere of the lighter, continental type. Therefore, the overall picture of the distribution of water and dry land would be as follows: first, there would be an equatorial *Ocean*, embracing the globe between 35°N and 35°S, with two antipodal continents in the temperature zones, which we can call the *Arctogea* and the *Antarctogea*. There would also be two polar mediterranean seas, lying in the midst of the two continents and two zonal belts of mountains and fractures arising at the boundary between the subsiding and the rising zones (Figure 6).

[1] It was H. Quiring who introduced into theoretical geology and geography the concept of critical zones of the terrestrial spheroid--that is, weakened zones of the lithosphere where the deforming stresses are maximal. Later on, M. V. Stovas (1951) introduced the analogous concept of critical parallels.

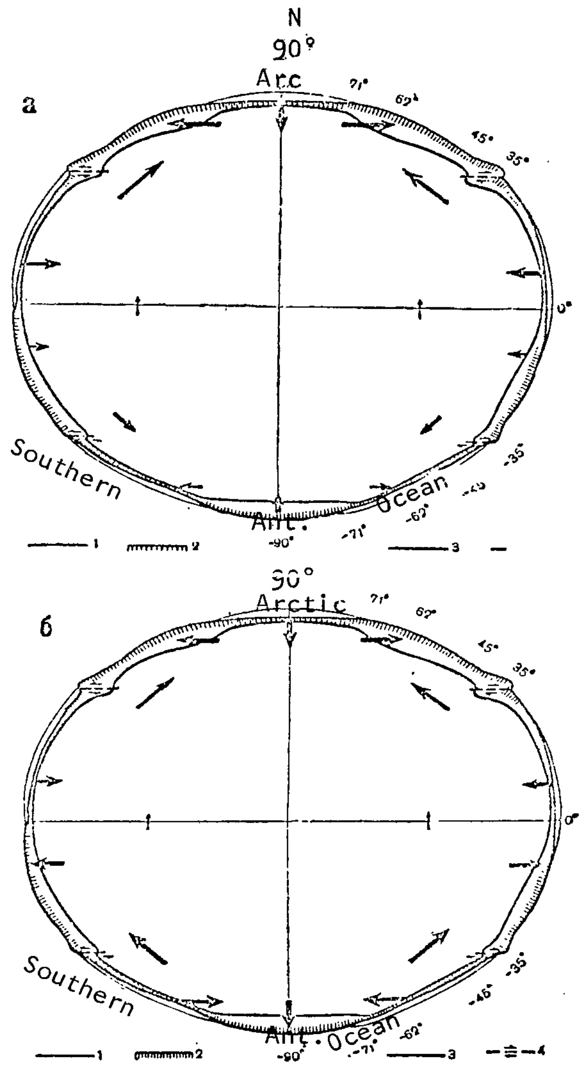


Fig. 8. Deforming Forces and Zonal Plan of the Earth with Secular Decrease in Polar Compression of the Northern Hemisphere, and with Relative Increase in Polar Compression of the Southern Hemisphere. Directions of Forces and Movements: a - Absolute, b - Relative. 1 - Hydrosphere; 2 - Lithosphere; 3 - Lower Boundary of the Earth's Crust (Mohorovivic Discontinuity); 4 - Abyssal Fractures.

In the event of prolonged increase in polar compression, the distribution of continents and oceans would be precisely the opposite: the equatorial zone would then comprise a continental belt, and the temperate zones would be occupied by a *Northern Ocean* and a *Southern Ocean*; and finally, at the poles, instead of land-surrounded seas, there would be two sea-surrounded continents (Figure 7).

Comparing the schemes of Figures 6 and 7 with the continental distribution which we know today, one can come to these quite curious conclusions: 1) the Northern and Southern Hemispheres of the earth, viewed as *a whole*, correspond neither to Figure 6 nor to Figure 7, although 2) the Northern /36 Hemisphere does in fact resemble the scheme of Figure 6 (the case of secular reduction of polar compression, while the Southern Hemisphere resembles the scheme of Figure 7 (the case of secular increase of polar compression; obviously, such a surprising discrepancy can be interpreted in various ways, but the most probable explanation is that 4) during the process of the secular reduction of polar compression, the Northern Hemisphere advanced more rapidly than the Southern. The cause of such an unequal rate of change in the volumnar and polar compression of the two hemispheres may be found in asymmetrical rotational forces (See above) acting as a brake upon the compression of the Northern Hemisphere, and accelerating the compression of the Southern. Therefore, the total volumnar compression of the Southern Hemisphere would advance more rapidly than that of the Northern, while the polar compression of the Southern (α_S) would be relatively greater than that of the Northern (α_N), on account of which there would arise a polar asymmetry in the figure of the earth: $\eta = (\alpha_S - \alpha_N)/2$.

Figure 8 is an illustration of the distribution, relative magnitude, and direction of the deforming forces for the asymmetrical case. It is of interest that in this scheme the belts of mountains and fractures are not in balance--the mountain belt of 35°N is better developed than its southern antipode. It is evident that here we have a sufficiently close correspondence between the theory and the facts of zonal distribution of the main forms of terrestrial relief. However, the scheme we have adduced fails to supply an answer to some of the questions arising in connection with the structure of the terrestrial surface.

For an understanding of nonzonal meridional and segmentary patterns of planetary relief, it is necessary to make allowance for the triaxiality of the figure of the earth, and for possible changes in that triaxiality during the course of geological history.

What are the causes of this triaxiality? Let us try to answer this /37 question by studying the history of the "double planet"--Earth-Luna.

The Past History of the Dual Planet Earth-Luna; Consequences Thereof

Our "eternal" satellite, the moon, has evidently not always been with us. The moon was evidently formed during an early pregeological stage of terrestrial history, before the young earth had developed its "skin", which we call the earth's crust. By the time of the formation of the moon, the earth had already achieved an age of 0.8 - 1.0 billion years, having evolved, during that period, from the primordial preplanetary gas-and-dust cloud which was the cradle of every planet in the solar system[1]. An important point is that during the formation of the dual planet Earth-Luna, the component parts were very close to each other--the distance was a little more than two and one-half earth radii[2].

The common birth of the earth and the moon (and therefore the coincidence of the earth's period of axial rotation and period of revolution about the earth), which is quite consistent with the cosmogonic theory of O. Yu. Shmidt, might have been the ultimate cause of interesting geological effects. The unique conditions during the initial history of the earth necessarily left some traces on the subsequent development of the planet, both as regards surface features and as regards underlying structures.

Let us assume that the earth and the moon move around a common center /38
of mass, just as if they were joined by an inflexible rod, and also that the centers of the earth and of the moon both lie on a projection of the equatorial plane of the earth[3]. Let us assume, further, that the moon is at the zenith for a certain definite point W lying at the intersection of the equator and the 165th meridian of west longitude. Then, for the antipodal point E (0°N, 15°E), the moon will be at the nadir. Since the tide-forming force is inversely proportional to the cube of the distance between celestial bodies, decreasing the earth-moon distance by a factor of 1/n will mean increasing that force by a factor of n^3. Therefore, the attraction of the

[1] Ye. P. Razbitna (1954) estimates the age of the moon to be 85% that of the earth, on the basis of O. Yu. Shmidt's theory. Assuming the age of the earth to be (6.5 - 5) $\cdot 10^9$ years (here the upper figure is that of Shmidt, 1955, the lower that of A. P. Vinogradov, 1955), we must conclude that the moon is 0.0 - 0.8 billion years younger than the earth.

[2] The dual system Earth-Luna could not have been formed if the distance were smaller than this, as was demonstrated by the astronomer Roche in 1850--for the moon would have been destroyed by the catastrophic tidal action of the earth. It is precisely for this reason that we cannot entertain the hypothesis that the moon was formed by the tearing off of a piece of the earth's mass. Similar hypotheses were made by G. H. Darwin and N. I. Leonov (1949). We cannot acknowledge the validity of any geological conclusions based on such hypotheses

[3] According to G. Kuiper (1956), the satellites were formed through gradual accumulation of solid particles *in the equatorial planes* of the primary planets.

moon must have caused a powerful initial deformation of the body of the earth--a special sort of tide in the form of two tidal crests communicating to the figure of our planet an elongation directed toward the moon (Figure 9). The maximum height of the tidal wave was achieved at points W and E, the maximum depth at the circle of meridian 105°E - 75°W. This was not a liquid tide, since the hydrosphere which surrounds the solid portion of the earth today obviously did not then exist; it was a tide in the predominantly solid portion of the planet, which, here and there, may have contained some fairly extensive molten portions of radiogenic origin. As a consequence of the proximity of the moon and the earth, the heights of the two waves were not the same--the higher was in the sublunar hemisphere, the lower in the opposite hemisphere. This inequality of the hemispheres, under conditions of the joint formation of the earth and its near neighbor the moon, may have been very large (Figure 10). The "one-sided" tidal effect of the moon on the earth evidently continued a long while, and this may have led to a quite profound asymmetry of mass distribution within the tidal triaxial ellipsoid with respect to the meridional plane perpendicular to the line joining the centers of the earth and the moon.[1] As a result of further development of the earth-moon system, there appeared, first of all, an imbalance (asynchronicity) of the periods of axial rotation of the earth and the rotation of the moon around the earth, and, secondly, an increase in the radius of the lunar orbit.

Precisely what could have produced these events? Evidently only an increase in rotational velocity, and, consequently, a decrease in the earth's period of rotation as a result of its mean radius and consequent acceleration of the moon's motion around the earth. By Newton's third law, both of the two tidal protuberances on the earth formed by the moon in their turn exert a gravitational attraction upon the moon. The attraction of the nearer protuberance will produce an acceleration, that of the farther one a retardation, of the orbital motion of the moon. But since the attraction of the protuberance nearer the moon is stronger, the moon's motion becomes progressively faster, and the satellite begins to move away from the earth. Thus, the lunar orbit describes a sort of spiral in time and space. However, since according to Kepler's third law the square of the period of the moon's rotation is proportional to the cube of its distance from the earth, then, along with increase in the radius of the lunar orbit, there will be a decrease in the moon's orbital velocity. Meanwhile, the gravitational action of the moon on the tidal protuberances on the earth will lead, at first, to a sharp reduction in the rate of increase in rotational motion, and later on to an actual reduction of that motion, and, consequently, to an increase in the earth's rotation period (Figure 12). /41

Before the formation of the moon, and also in the period when the moon circled the earth once a day, no such situation as we have described here existed. The formation of the moon, therefore, was a revolutionary, critical event in the history of the earth.

[1] A direct estimate of the duration of this influence is difficult to make. Indirect considerations (See pages 3 and 4) suggest a period of 10^3 - 10^6 years.

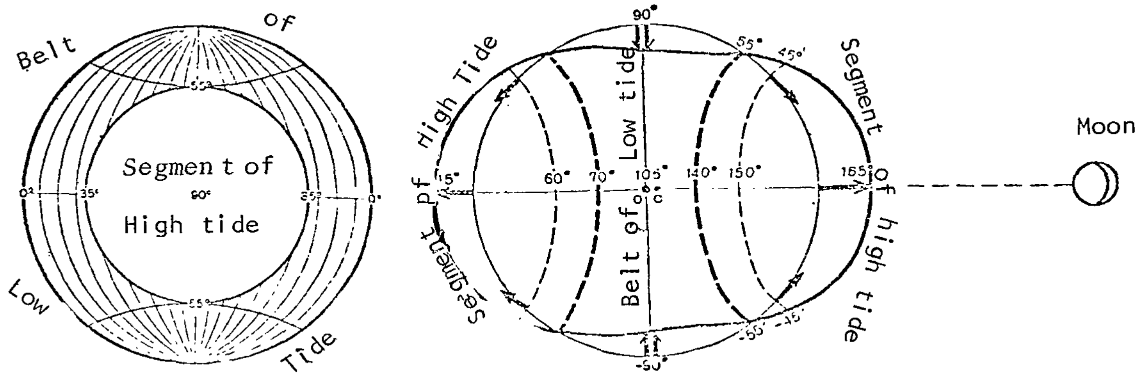


Figure 9. Asymmetrical-triaxial Tidal Ellipsoid. O - Center of Mass of Earth; C - Center of Mass of Earth and Sun. The Figures Along the Equator on the Left Denote the Distances of the Circles and Centers of Deformation From the Meridian of the Minor Axis of the Tidal Ellipsoid; On the Right they Denote the Distances from the Greenwich Meridian. The Arrows Denote the Position, Direction and Relative Magnitude of the Maximal Vertical and Horizontal Components of the Tide-Forming Forces.

Following the divergence of the periods, the prolateness of the planet and the nonuniformity of its distribution of mass in the longitudinal direction gradually disappeared, since the unstable, asymmetrical triaxial figure of the earth was striving to assume a more stable configuration. /42 The radial and tangential forces arising during this process are shown in Figure 13. If, at this stage in its development, the earth had been molten-liquid in structure, then the tide-induced triaxiality and asymmetry of the Eastern and Western Hemispheres, along with the associated stresses in the /43 body of the planet and in the lithosphere, would have been eliminated rather quickly, and certainly would not have been maintained until our own time. But actually the process of evening out the major and minor axes and the asymmetry of the major semiaxes of the tidal ellipsoid were drawn out over a very long period lasting even to the present day, and showing itself in the most varied sorts of tectonic phenomena. The pulsational, oscillatory character of this

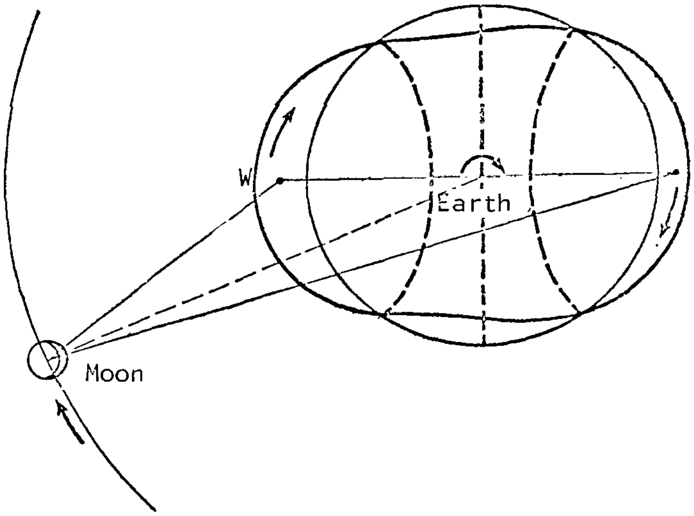


Fig. 11. The Gravitational Force Exerted by Terrestrial Protuberances From Side W is Greater Than That From Side E, so that the Earth Accelerates the Orbital Velocity of the Moon. The Gravitational Force Exerted by the Moon at W Produces a Deceleration, and That at E, an Acceleration, of the Earth's Rotation. But the Effect of the Nearer Protuberance (W) is Greater Than That at E, and Therefore the Net Effect is That the Moon Slows the Earth's Rotation.

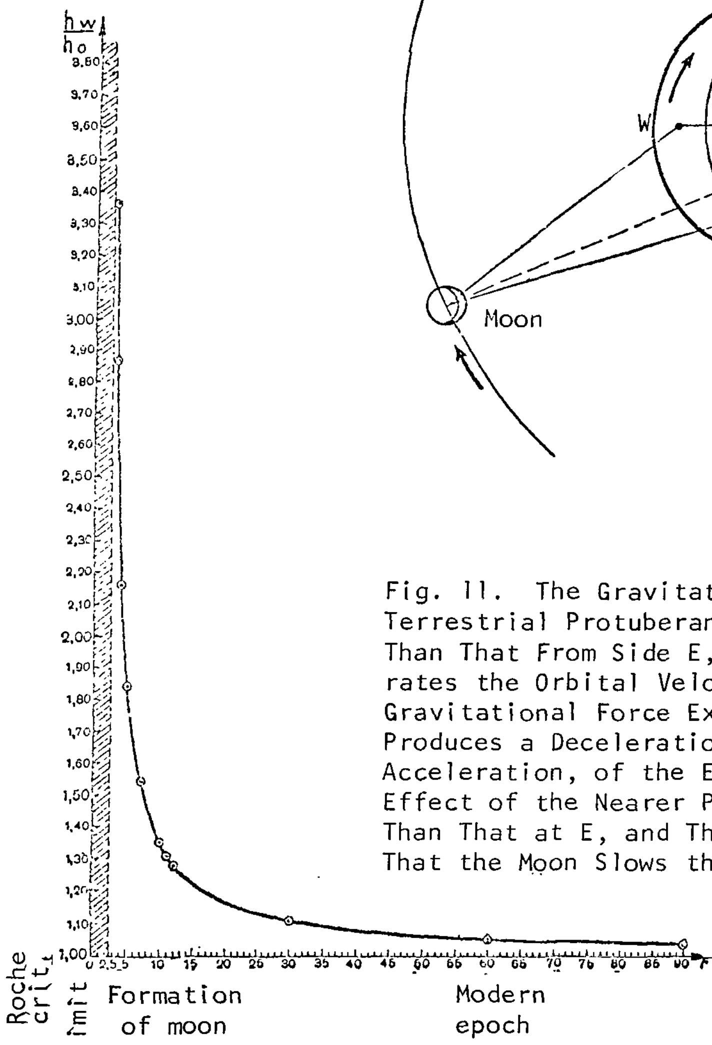


Fig. 10. Illustration of the Change in the Asymmetry of the Major Axis of the Tidal Ellipsoid of the Earth, as a Function of the Earth-Moon Distance: h/h_0 is the Ratio of the Heights of Tides at Those Points Where the Moon Is at the Nadir and the Zenith; r is the Earth-Moon Distance in Fractions of the Earth's Radius. The Stipled Portion Represents Distances Beyond the Roche Limit.

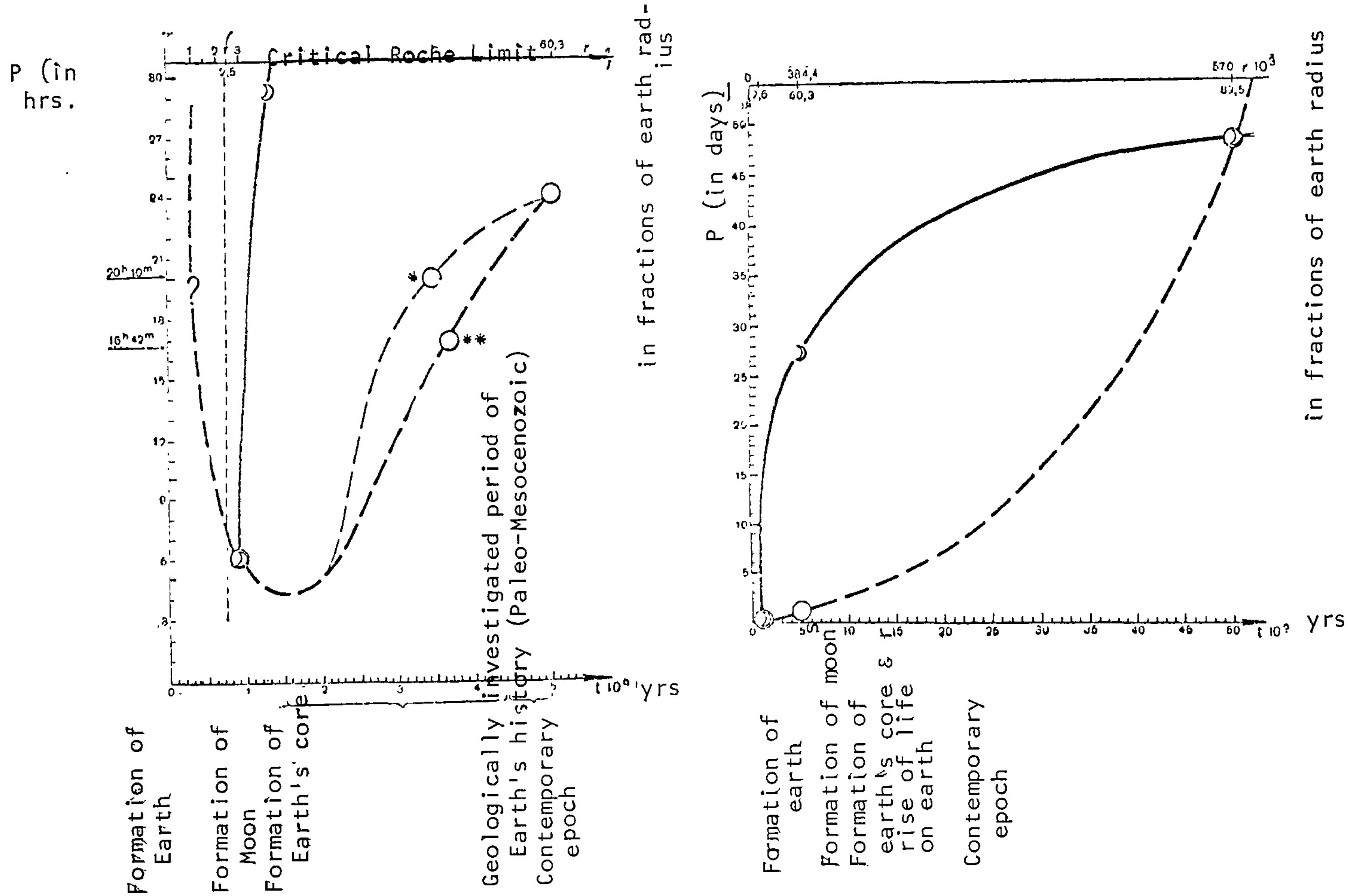


Fig. 12. Graphs Illustrating the Past and Future of the Earth-Luna Double Planet; t - Time, Beginning with the Formation of the Earth, in Billions of Years; P - Periods of Axial Rotation of the Earth (Broken Line) and Orbital Movement of the Moon (Solid Line) Around the Earth; r - Distance Between the Earth and the Moon, in Kilometers, and in Fractions of the Earth's Radius; * - Variation in the Period of Axial Rotation of the Earth (First Approximation); ** - Variation in the Period of Axial Rotation of the Earth (Second Approximation).

grandiose process affecting the entire planet was associated with both internal and external gravitational influences of the moon and of the sun, which hindered attenuation of the process and a final resolution of the longitudinal nonhomogeneity in the distribution of mass.

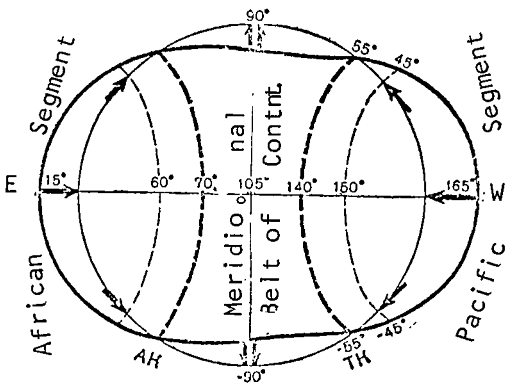


Fig. 13. Distribution of the Deforming Forces in the Body of the Asymmetrical-Triaxial Earth (With Decrease in Equatorial Compression and East-West Compression) With Respect to the Meridional Plane of the Minor Equatorial Axis:
AK - Fractures Surrounding Africa
TK - Fractures Surrounding the Pacific.

In view of the fact that the major axis of the triaxial terrestrial ellipsoid coincides with the Pacific - Africa axis, and the conclusions that derive from that fact, the following basic conclusions are justified. The most important tectonic consequences of equalizing the major and minor axes were as follows: 1) the laying of the Great, or Pacific Ocean, enclosed between critical circles; 2) the rise, within this belt, of the continents of Eurasia, Australia, Antarctica and the two Americas; 3) the formation of antipodal Circum-Pacific and Circum-African belts /45
of mountains and fractures within the zones of influence of the western and Eastern critical circles[1]. The asymmetry of the major semiaxes and its reduction are associated with several factors: 1) the tectonic and seismic asymmetry of the Circum-Pacific and Circum-African mountain belts; 2) the relative retardation of the African segment as compared with the Pacific in the process of its general subsidence--a factor which occasioned the appearance of a positive form of planetary relief (the continent of Africa, consisting of structures antipodal to the Great Ocean; /46

[1] These critical lines are parallel to the meridian of the minor equatorial axis (105 - 75°), being distant from it by an angle of 35°. Their direction varies from the meridional (close to the equator) to the east-west (close to the 55th parallel, north and south). Subsequently, in this text we shall refer to these lines as "submeridional".

3) the formation (compensational) on the periphery of the African continent of the Indian and in part the Atlantic Oceans, and also the Mediterranean Sea; and 4) the general asymmetry of the geological history of the Pacific and African Hemispheres, as expressed in the well-known contrast of their structural developments.

Thus, the formation of a meridional continental belt, the Great Ocean, and Africa, appears to this writer to have been induced by the action of the moon. In the past history of the development of the Earth-Luna double planet is hidden also the answer to the riddle of the Circum-Pacific and Circum-African belts of mountains and Fractures.

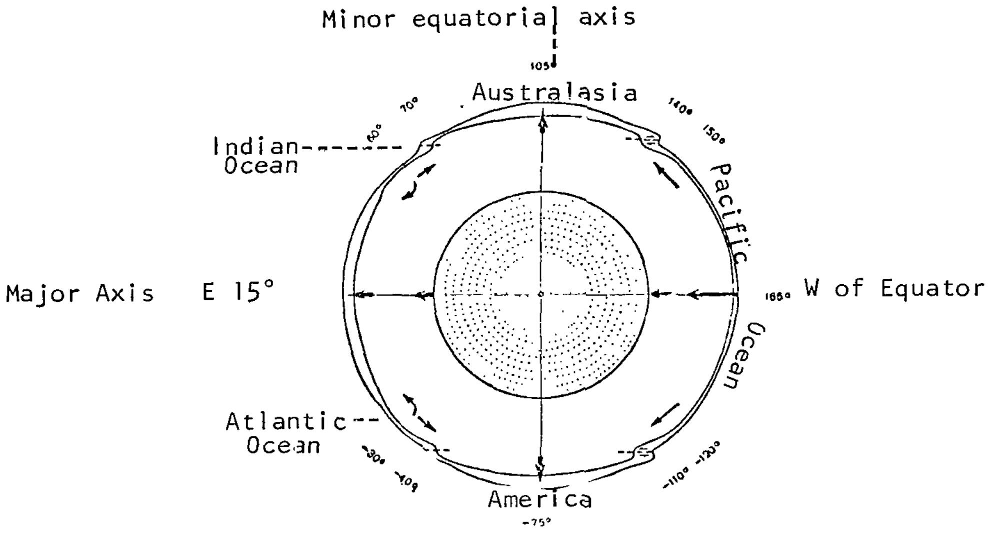


Fig. 14. Abyssal Movements Within the Mantle, and Deformations of the Upper Portions of the Mantle Associated With Primary Triaxiality and Asymmetry of the Earth's Figure Induced by the Action of the Moon.

Active Circles and Centers of Deformation of the Terrestrial Ellipsoid

On account of the constantly accumulating changes taking place in the internal structure of the earth, the dimensions and rotational velocity of the planet have inevitably become quite different from what they originally were. More specifically, this has been due to changes in the planetary figure as regards the appearance of new values for κ_i, R and ω--a reconstruction accompanied by a shifting of masses affecting every layer of the planet.

TABLE 2

Space and Time Relationship Between Tectonic and Regressive-Transgressive Movements Associated With Reduction of Polar Compression

(After H. Quiring, 1921, with Modifications)

Geosphere	Equatorial Zone	Temperate Zone Above 35°	Polar Zone
	Absolute Movements		
Subcrustal substance (asthenosphere)	Subsidence	Uplift (insignificant)	Uplift
Earth's crust (lithosphere)	Subsidence (insignificant)	Uplift (insignificant following subcrustal)	Uplift (isostatically following subcrustal masses)
Ocean, (hydrosphere)	Subsidence	Uplift, only to some degree pushing the lithosphere, and in some places overtaking it; epicontinental inundation	Uplift (with respect to the lithosphere, as in the temperate zone).
	Relative Movements (with respect to sea level)		
Lithosphere	Uplift followed by subsidence	Subsidence followed by uplift	Subsidence followed by uplift (the former predominant)

The transformation began first in the atmohydrosphere, the earth's most mobile portion, then spread to the most pliable part of the lithosphere, where it occasioned the beginning of tectonic movements (Table 2). Movements of the mantle were most pronounced in the subcrustal portion, where the thermal conditions for shifting the component masses of the mantle (which, on the whole, were solid) were evidently most favorable. Nevertheless the movements in the subcrustal level appeared later than those in the atmohydrosphere. As is evident from Figures 8 and 13, maximal radial and tangential displacements arising during change in the earth's figure are disposed in belts which are "drawn to" certain definite active circles and centers of the terrestrial ellipsoid. These active circles, at which the radial movements achieve a maximum, are called "extremal", and the circles which interlock with them, where the radial movements reverse their sign, are called "critical" (Fig. 15). /48

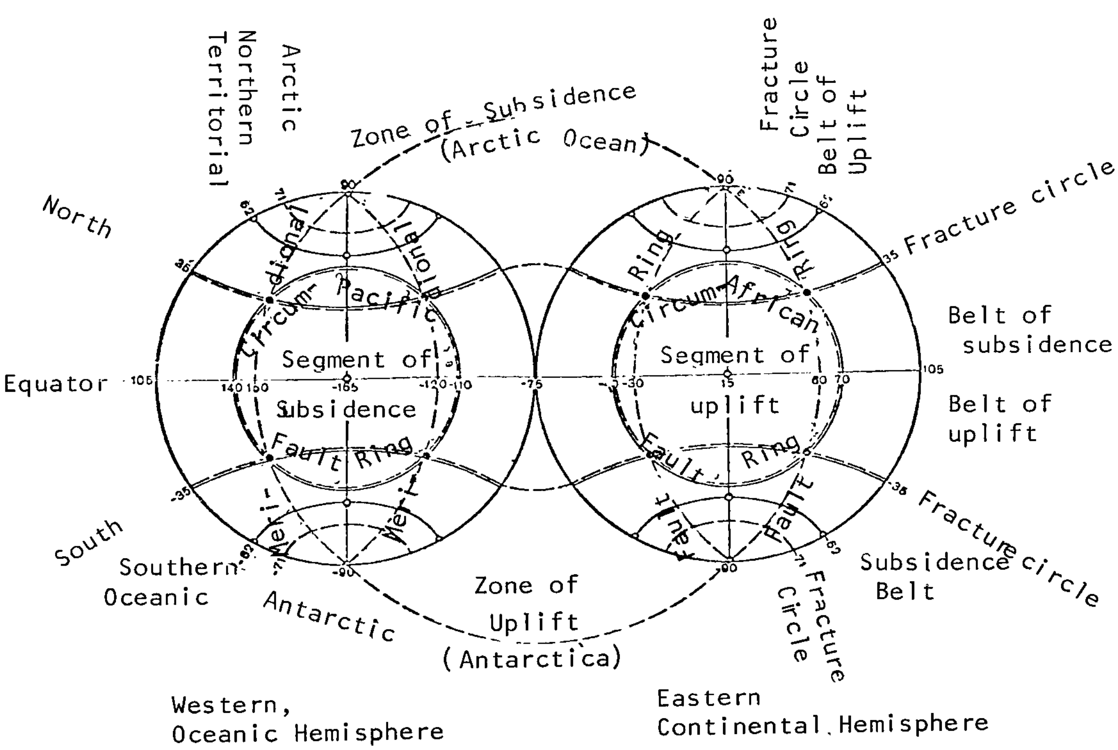


Fig. 15. Circles and Deformation Centers of the Asymmetrical-Triaxial Cardioidal Earth.

Extremal circles of the terrestrial ellipsoid:

1) $\phi_e = 0°$ (equator),

2, 3) $\phi_e = \pm 61° 52' 28''$ ($\pm 62°$) are the northern *epeirogenic* and the southern *thalassogenic parallel*,

4) $\lambda_e = 105° - 75°$ is the *epeirogenic meridian*. This meridian is a physical entity separating the Western and Eastern hemispheres--not a fictitious entity like the meridian of Greenwich.

Extremal centers:

5, 6) $\phi_e = \pm 90°$ (North and South Poles);

7, 8) ($\phi_e = 0°$, $\lambda_e = 15°$), ($\phi_e = 0°$, $\lambda_e = -165°$) are the *poles of the Eastern and Western Hemispheres*,

9, 10) ($\phi_e = 62°$, $\lambda_e = 105°$), ($\phi_e = 62°$, $\lambda_e = -75°$) are the *Siberian and Canadian epeirogenic centers*.

Critical circles:

11, 12) $\phi_e = \pm 35°15'52''$ ($\pm 35°$) are the *northern and the southern orogenic parallel*[1];

13, 14) $\phi_e = \pm 71°39'$ ($\pm 71°$) are the *northern and the southern circum-polar parallel*--the theoretical boundary between the northern continents and the polar ocean, and the Southern Ocean and the Polar Continent;

15, 16) *the western (Circum-Pacific) and eastern (Circum-African) orogenic circles*--the theoretical limit between the Pacific and African segments, on the one hand, and the meridional belt of continents, on the other; these circles, as a result of the interaction of the extremal centers (5, 6) with the critical centers (11, 12, 15, 16), form the *critical meridians* of maximum tangential stresses:

17, 18) $\lambda_0 = 60°$--$120°$, $150°$--$30°$.

As a result of the imposition and interaction of zonal and meridional stresses at points where active parallels and active meridians intersect, there arise centers of deformation, where movements of the lithosphere are greatest. Interaction between zonal and meridional tectonic waves results /50

[1] Epeiro-, thalasso- and orogenesis, are, respectively, the processes of the formation of continents, oceans and mountains.

in unevenness of deformation of the lithosphere, even at the boundaries of one and the same tectonic belt. This accounts for the variegation and mosaic character (isometricity) of the plan of terrestrial tectonics, and the zonal provincial character of the relief of the earth's surface.

The Effect of Twisting of the Earth's Surface Around the Axis of Rotation

Apart from the tangential forces described above (associated with change in the figure of the earth, and directed along the meridians and parallels or obliquely to them) there exist others which, depending upon the direction of the radial movement (uplift or subsidence) displace masses to the east or to the west. These forces arise upon changes in the linear rotational velocity (u) which are caused by shifts in the angular velocity of rotation (ω) or in the radius of the parallel (r). It is known that

$$u = \omega r, \tag{9}$$

whence

$$\underbrace{\frac{\Delta u}{u}}_{\substack{\text{relative change}\\ \text{in linear velo-}\\ \text{city of rotation}}} = \underbrace{\frac{\Delta \omega}{\omega}}_{\substack{\text{relative change}\\ \text{in angular velo-}\\ \text{city of rotation}}} + \underbrace{\frac{\Delta r}{r}}_{\substack{\text{relative change}\\ \text{in radius of}\\ \text{the parallel}}}. \tag{10}$$

When there is radial subsidence (or uplift) of any mass of the planet, there arises an additional tangential force which shifts the mass to the east (or west). The magnitude of that force (F) is defined by the following:

$$F = m\left(r\frac{\Delta\omega}{\Delta t} + \omega\frac{\Delta r}{\Delta t}\right), \tag{11}$$

where m is the mass, $\Delta\omega/\Delta t$ is the acceleration (or deceleration) of rotation, and $\Delta r/\Delta t$ is the rate of change of the radius of the parallel.

Applying these relations to secular radial movements of zones of the terrestrial cardiod, and assuming that relative radial uplifts of the lithosphere in the Southern Hemisphere are maximal at about the 60th parallel, we /51
can formulate the following law: within the general rotational movement toward the east is included a relative lag of the northern zones and a relative advance of the southern zones. Moreover, these two phenomena increase in magnitude as one moves from the equator to parallel 62°, and from the poles to

parallel 62°. There is thus, a relative shift of both hemispheres along the "rails" of the parallels in the 60's: the northern Hemisphere shifts to the west, and southern to the east. This produces an S-shaped deformation of the entire system of meridional and submeridional active circles, so that the earth's surface experiences a twisting around the terrestrial axis. This phenomenon has been of enormous importance in shaping the general features observed on the planetary surface today (Figure 16).

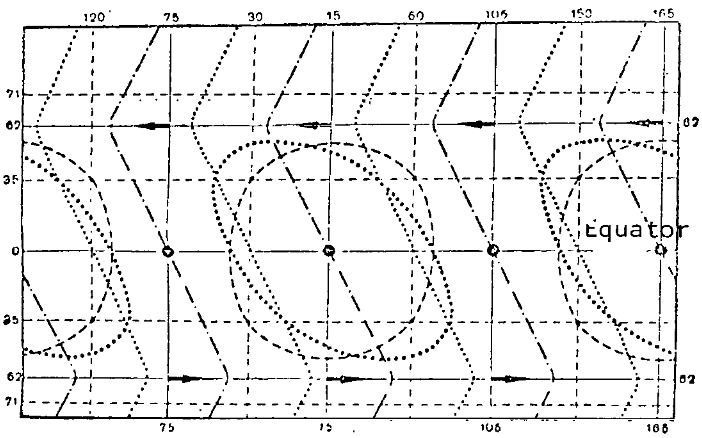


Fig. 16. S-Shaped Deformation of the Axes of the Structural Belts of the Earth Arising From the Twisting Effect.

The Effect of Equatorial Acceleration

In addition to the influences described above, the lithosphere obviously is subject to the action of *equatorial acceleration*. This is associated with the general subsidence of the equatorial belt during secular reduction of polar compression and the approach of the equatorial masses of the lithosphere toward the planet's rotational axis. Those masses, /52
as a result, acquire additional rotational velocity. The possible effects of this equatorial acceleration are the following:

1) the crescent shape of South America and Africa, which are convex toward the east and concave toward the west;

2) the shift of the genetic (and geometric) centers of South America and Africa eastward from the meridional axes (75° W and 15°E); and

3) the "rotation" of Australia in a clockwise direction and of India in the opposite direction.

The Effect of Successive Sectorial Compressions and Stretchings of the Lithosphere

From the law of the preservation of rotational moment we can deduce still another interesting tectonic result. Let us consider the interaction of three mutually perpendicular, shifting, sectors of the lithosphere, the central rising one being bounded by one on the east and another on the west. Since the central (continental) sector acquires a tendency to shift to the west, while the outer (oceanic) sectors tend to shift to the east, it is obvious that in such a situation the western boundary of the continent will be subjected to bilateral compression, the eastern boundary to bilateral stretching in the east-west direction. On the basis of this mechanism we can explain the earth's meridional and submeridional fractures, foredeeps, island arcs and chains, and archipelagoes--structures which, as is well-known, are found predominantly on the eastern sides of continents. We can also explain, in particular, the stretching of the lithosphere and the presence of the rift valleys of East Africa.

The Pulsating Body and Figure of the Planet. Pulse-Wave Oscillatory Movements

The pulsation geotectonic hypothesis in its classical form (W.H. Bucher, 1933, M. A. Usov, 1940, V. A. Obruchev, 1940) is unable to explain the regular distribution of radial and tangential stresses which we observe in a few predominant directions, without invoking the factor of terrestrial rotation. Generally speaking, the tangential stresses which arise with earth pulsation are equal in all directions. /53

Consequently, if we accept the pulsation hypothesis, then the formation of geosynclines and the distribution of mountain systems have to be regarded as purely random phenomena. But if that were so, the structure of the earth's various belts, oriented as they are with respect to the rotational axis, would be incomprehensible. It is scarcely surprising that neither Bucher's nor Obruchev's formulations explain the structure plan of the earth, or even take it into account.

The secret of the formation of the structural plan of the lithosphere is simply that earth pulsations have exerted an effect on terrestrial rotation. This effect is defined by the law of the conservation of moment of rotation:

$$L = \varkappa M R^2 \omega \left(1 + \frac{2}{3}\alpha\right) = \text{const},$$

where κ is a coefficient depending on the structure of the planet (distribution of densities along the radius)[1], M is the mass of the earth, R is the mean radius of the earth, ω is the angular velocity of rotation, and α is the polar compression.

Actually, any change in the mean radius or in the distribution of densities within the earth will produce a change in the angular velocity of rotation. If the radius contracts, the velocity will increase, and vice versa. On the other hand, compaction of the earth's interior material, which occurs in the course of time (as a result of redistribution of masses along

[1] The value of this coefficient lies somewhere between 0.400 (assuming uniform distribution of density along the radius) and 0.133 (assuming total mass to be at the center). The actual figure, for the earth as it exists today, is 0.331. For planets of our own solar system, the highest value is found in the case of Mars (0.356) and the lowest value in the case of Saturn (0.1683).

the radius and increase in densities of the central parts of the planet) leads to a reduction of the structural coefficient κ, and, consequently, to acceleration of rotation, accompanied by an increase in polar compression and asymmetry in the figure of the earth.

The epochs of terrestrial expansion, on the contrary, are accompanied by stretching of the lithosphere, deceleration of rotation, and reduction of polar compression and asymmetry of the planet--which is, of course, only another change in the terrestrial figure. The figure of the earth at such times is closer to the spherical than during periods of more marked compression, when the polar oblateness is particularly great. /54

One might expect that tidal braking of terrestrial rotation was greater during periods of expansion than during periods of compression. Actually, the magnitude of tidal friction depends pretty largely upon the area of shallow water on the planet, and this is a factor which has varied over the course of geologic history: specifically, it has been greater during epochs of extensive marine transgression (which coincide with epochs of expansion), and smaller during epochs of marine regression (which coincide with epochs of compression).

Thus it is clear that epochs of compression and expansion are directly correlated with epochs of corresponding alteration of rotational velocity, polar compression, and asymmetry of the planet's figure. This is precisely what the tectonic hypothesis, which we can call the rotation-pulsation hypothesis, points directly to. The hypothesis embraces not only earth pulsations, but also the rotation-induced pulsations of the planet's figure.

We shall apply the term "pulsational" to those single-valued, oscillatory movements which are common to the whole surface of the planet, and which proceed in the direction of the earth's radius, and the term "wave-pulsational" to those multiple-valued, superimposed on the former and interlocking among themselves, which are associated with pulsations of the planet's figure. Pulsational movements, if they are opposite in sign (subsidence - uplift) are also different in time, for they relate to different epochs, whereas wave-pulsational movements opposite in direction are simultaneous. Consequently, movements of the first group can succeed one another only in time but not in space; while those of the second group may succeed each other in both.

The Fight Between Attraction and Repulsion--The Motive Power of Geotectonic Development

Secular tidal braking of the earth's rotation is three times as great as secular acceleration from the same cause. This means that the present-day action of external factors on terrestrial rotation (the gravitational attraction of the moon and sun, tidal friction of the atmosphere and hydrosphere, etc.) is greater than the effect of internal forces (the gravitational attraction toward the common center of mass, physico-chemical processes of the compaction and differentiation of matter, etc.) The interaction between /55 these opposing influences--in other words, the eternal fight between attraction and repulsion[1]--proceeding either with temporary preponderance of one, or with temporary equilibrium--is the cause of the uneven course pursued by the never-ending spiral of tectonic development. Let us trace out this process as exemplified by the formation of mountains in the critical zones of the 35th parallels (N and S).

With *constant equilibrium* of the forces of attraction and repulsion (in the case of the earth this would mean that $\Delta\omega$ remains equal to zero and that there is no axial rotation), no mountain belt could, in general, be formed at or near the northern and southern 35th parallels. But this extreme case is purely theoretical (since it excludes the factor of development) and is not actually possible in nature.

If, on the other hand, equilibrium between attraction and repulsion is lacking (by which we mean that one of the two--say repulsion--predominates, in which case $\Delta\omega$ is not equal to zero), then the formation of mountains will certainly take place. This was the situation which Ye. V. Bykhanov had in mind when he made the following noteworthy remark: "Mountains were formed on the surface of the earth in proportion as the rotation of the globe was retarded" (1877, p. 146). To this we can add that the formation was more intensive at the northern 35th parallel than at the southern (See Figure 8a).

Mountain-forming is most intense when the opposition between the forces of attraction and those of repulsion is acute (that is, when acceleration and deceleration occur in rapid alternation, and $\Delta\omega$ oscillates without achieving a fixed value--this represents a revolutionary-critical epoch in the history of the earth and living things. Such epochs, consequently, are distinguished /56
by the active manifestation of tectonic stresses, and movements and deformations both within the body of the planet and on its surface; they represent the times of greatest pulsation in the earth's volume, as well as maximal accelerations and decelerations of rotations and of the processes involved in change of the earth's figure.

Finally, during temporary equilibrium between the forces of attraction and the forces of repulsion (that is, when there is uniform rotation and $\Delta\omega$ is equal to zero), there occurs an interruption of mountain-building.

The leading role in this planetary mechanism of mountain-formation is played by the changes occurring in the centrifugal forces of rotation, which are indissolubly associated with oscillations of the planet's volume, with increase in gravitational compaction toward the center, with tidal influences, and, in particular, with secular deceleration of the earth's rotation as a result of tidal friction. All of these changes result in, and maintain, an

[1] Apart from the gravitational influence of external worlds, one can include here inter-particle (interatomic, interionic and intermolecular) repulsion. The existence of forces of inter-particle repulsion explains the thermal expansion of bodies.

eternal (and regular) alternation of subcrustal, crustal, atmospheric and hydrospheric movements, which , in the process of constant interchange of compression and expansion of the globe under the action of the forces of attraction and repulsion, result in mountain-formation and continual renewal of the aspect of the greatest mountain systems.

Thus, tectonic shifts within the body of the earth and the associated change and renewal of the structural forms of the earth's surface are distributed extremely unevenly, both in space and in time. In connection with this general unevenness in the development of our planet, there stand out *revolutionary-critical epochs*, just as on the surface of the earth we find *critical belts*, in which slow, secular quantitative changes, gradually building up and being resolved, give rise to qualitatively new forms.

LAWS OF THE FORMATION AND DISTRIBUTION OF CONTINENTS, OCEANS AND MOUNTAIN BELTS

CHAPTER 3

GEOGRAPHIC HOMOLOGIES

"Truth is the daughter of time,
not authority."

--Francis Bacon

Glancing curiously at a world map or globe, we frequently fail to think of the enormous labors, often associated with danger to life and limb, which were required of the army of investigators who toiled selflessly over a period of dozens of centuries to make possible such a picture of the lands and seas of the planet we live on. /57

Geographic discoveries have been of enormous significance; to a great degree they have furthered discoveries in other areas of science.

But to describe the surface of the earth and draw it on a map is only half of the business at hand. It is necessary, as well, to explain how the oceans appeared, why they are distributed as they are rather than in some other manner--in a word, it is necessary to answer a series of pretty difficult questions which cannot fail to be asked by any inquisitive person.

The key to understanding the distribution of the earth's continents and oceans is found in the so-called "geographic homologies", by which we mean similarities and correspondences in the distribution, outlines and relief of the continents and oceans[1]. /58

---

[1] The question of geographic homologies had already attracted the attention of ancient scientists. Strabo (63 B.C. - 20 A.D.), the Greek geographer and historian, wrote of them in his *Geography*. Following the long darkness of the Middle Ages the notion of geographic homologies was born again during the Renaissance, when the English philosopher Francis Bacon, that fierce fighter against medieval scholasticism and defender of the scientific outlook, brought it up in his *Novum Organum* (1620). Finally, Lomonosov (1763 a), quite independently of Strabo and Bacon, developed the idea of geographic homologies.

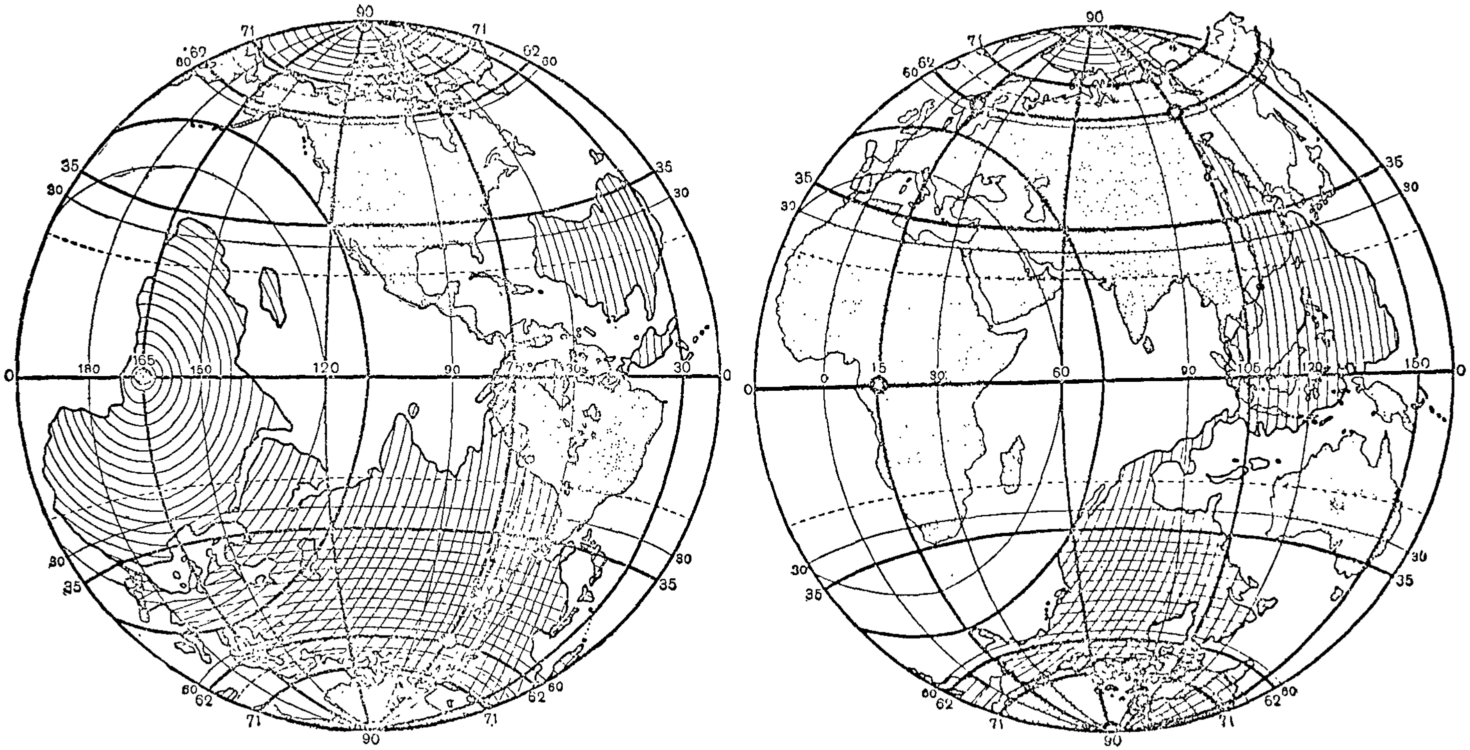


Figure 17. Antipodal Distribution of Continents and Oceans, Australasia and America. (After L. P. Shubayev, 1956, with the Addition of Active Circles and Centers).

The Antipodality of Oceans and Continents /59

The antipodal distribution of the continents and oceans is a very characteristic feature of the face of the earth. Draw an imaginary line through the center of the earth, and you will find that whenever one end emerges on dry land the other end will emerge in the sea, and vice versa. This statement is more convincing when demonstrated visually: roll a globe along a table top, and observe that two antipodes are rarely both dry land /60 or both water--only about once in 20 times does this occur.

"The antipodes of the continents are the oceans." This ancient maxim is very nearly correct, for Antarctica is balanced by the Arctic Ocean, Europe and Africa by the Great Ocean, the northern continents by the Southern Ocean, and North America by the Indian Ocean. It is only South America which fails to fit into this scheme--its antipode is the dry land of Southeast Asia (Figure 17).

Why Antarctica and the Arctic Ocean Are Antipodes; the Oceanic Character of the Southern Hemisphere and the Continental Character of the Northern Hemisphere

The antisymmetrical distribution of depressions and elevations on the earth's surface, like the associated antipodal distribution of continents and oceans, is especially well illustrated by the case of the polar regions. The Arctic is occupied by a circular, nearly closed circumpolar marine basin, the depth of which near the Pole itself is 4,300 meters (data of Soviet high-altitude expeditions of 1948 - 1957). The maximum depth of this ocean is 5,449 meters (A. F. Laktionov, 1960). The Arctic polar basin is essentially a mediterranean sea, since it is almost entirely surrounded by dry land.

Conversely, the Antarctic is occupied by a circular, circumpolar continent, whose altitude, at the South Pole, is 2,800 meters above sea level, and near the Pole of Inaccessibility 3,900 meters. Thus, in the northern polar region the surface of the lithosphere is almost 8.5 kilometers closer to the center of the earth than it is in the southern polar region. Thanks to this fact, and to the presence of a northern belt of continents and of the Southern Ocean embracing the two polar regions, not only the figure of the earth as a whole, but also that of the lithosphere, are heart-shaped (See Figure 8). It is interesting to observe that this cardiod quality is considerably more pronounced in the case of the lithosphere (See Figure 2). /61

The distribution of water (Table 3, Fig. 18), and the granitic and basaltic layers of the lithosphere (Figure 19-a and -b), and also the thickness of the earth's crust (Figure 20), are also subject to a general law: *between the 62nd parallels, north and south, continental masses are greater, and oceanic (aqueous and simatic) masses are smaller; but north and south of those parallels the reverse situation obtains.* Closely connected with this fact is a second characteristic feature of the surface of the earth--the pinching out of continents toward the south (Figure 21). This law reflects the oceanic character of the Southern Hemisphere and the continental character of the Northern Hemisphere--as it were, in three measurements of area and depth; moreover, it clearly emphasizes the antipodal relationship between the Arctic Ocean and the Antarctic Continent.

TABLE 3.

Parallel		Proportion of Belt Occupied By Sea	Proportion of Parallel Corresponding to Sea
Latitude	Polar Distance		
90° N	0°	0,902	1,000
80	10	0,703	0,720
70	20	0,286	0,463
60	30	0,427	0,353
50	40	0,477	0,407
40	50	0,571	0,527
30	60	0,624	0,536
20	70	0 737	0,677
10	80	0,772	0,710
0	90	0,765	0,771
10° S	100	0,780	0,786
20	110	0,768	0,777
30	120	0,886	0,791
40	130	0,969	0,951
50	140	0,992	0,972
60	150	0,905	1,000
70	160	0,310	0,597
80	170	0,029	0,125
90	180		0,000

The remarkable equality and antipodal relationship between the northern polar ocean and the southern polar continent (a common area of 13,100,000 square kilometers) are the result of compensatory movements of material which occurred in the polar regions in connection with the formation of the northern /62 continental belt and the Southern Ocean (See Figure 8-b). The boundary of these compensatory vertical movements is the so-called "circle of symmetry of polar countries" $\phi_0 = 71°39'$, which is defined as the boundary within which the whole of the Arctic Ocean and of the Antarctic Continent could be included if they were evenly distributed around the poles (in the form of perfect circular circumpolar zones. Not only a significant part of Antarctic coastal areas, but even the extreme northern tips of the northern continents and of the Antarctic Continent, are located close to these critical boundaries:

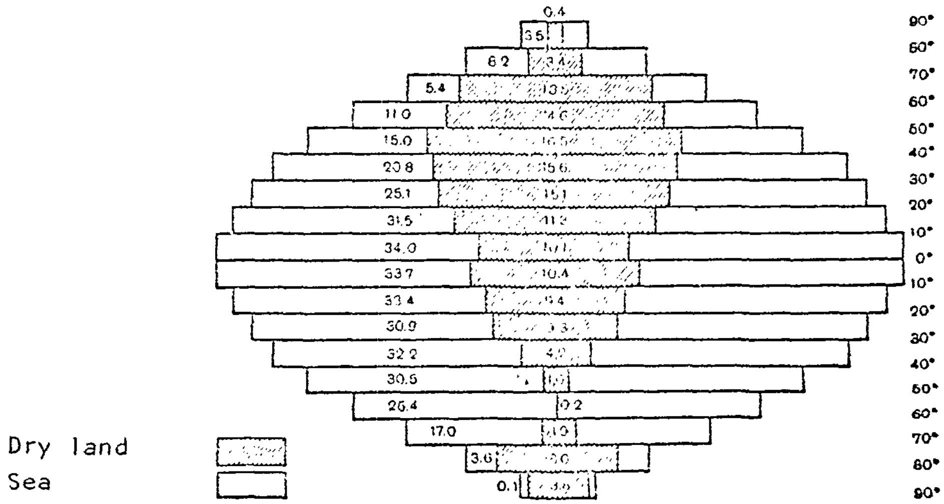


Figure 18. Asymmetry of the Zonal Distribution of Dry Land and Sea on the Surface of the Earth. (Compiled by L. P. Shubayev, 1956). The Numbers in the Body of the Diagram Denote Areas in Millions of Square Kilometers.

Cape Murchison (North America)........71°50' N
North Cape (Europe)..................71°08' N
Cape Chelyuskin (Asia)................77°43' N

Consequently, not only the polar asymmetry of the figure of the earth, but also the antipodal character and the equality of areas of the Arctic Ocean and the Antarctic Continent, are the result of differing rates of secular reduction of polar compression in the two hemispheres--greater in the northern and lesser in the southern. /63

What are the main reasons why the Northern Hemisphere is predominantly sialic (granitic-basaltic) and continental in character, and the Southern Hemisphere simatic (ultrabasic) and oceanic? Why is the thickness of the earth's crust several times greater in the Northern Hemisphere than in the Southern?

One reason is to be found in contrary movements within the earth's shell in the two temperate zones: in the Southern Hemisphere these movements, being downward, have retarded the differentiation of material and the formation of the crust; in the Northern Hemisphere, being upward, they have accelerated those processes. V. A. Magnitskiy (1952, 1953, 1955, 1958) has suggested that the basic geochemical reaction which supplies free silica (SiO_2) from the depths of the earth for the formation of the granitic

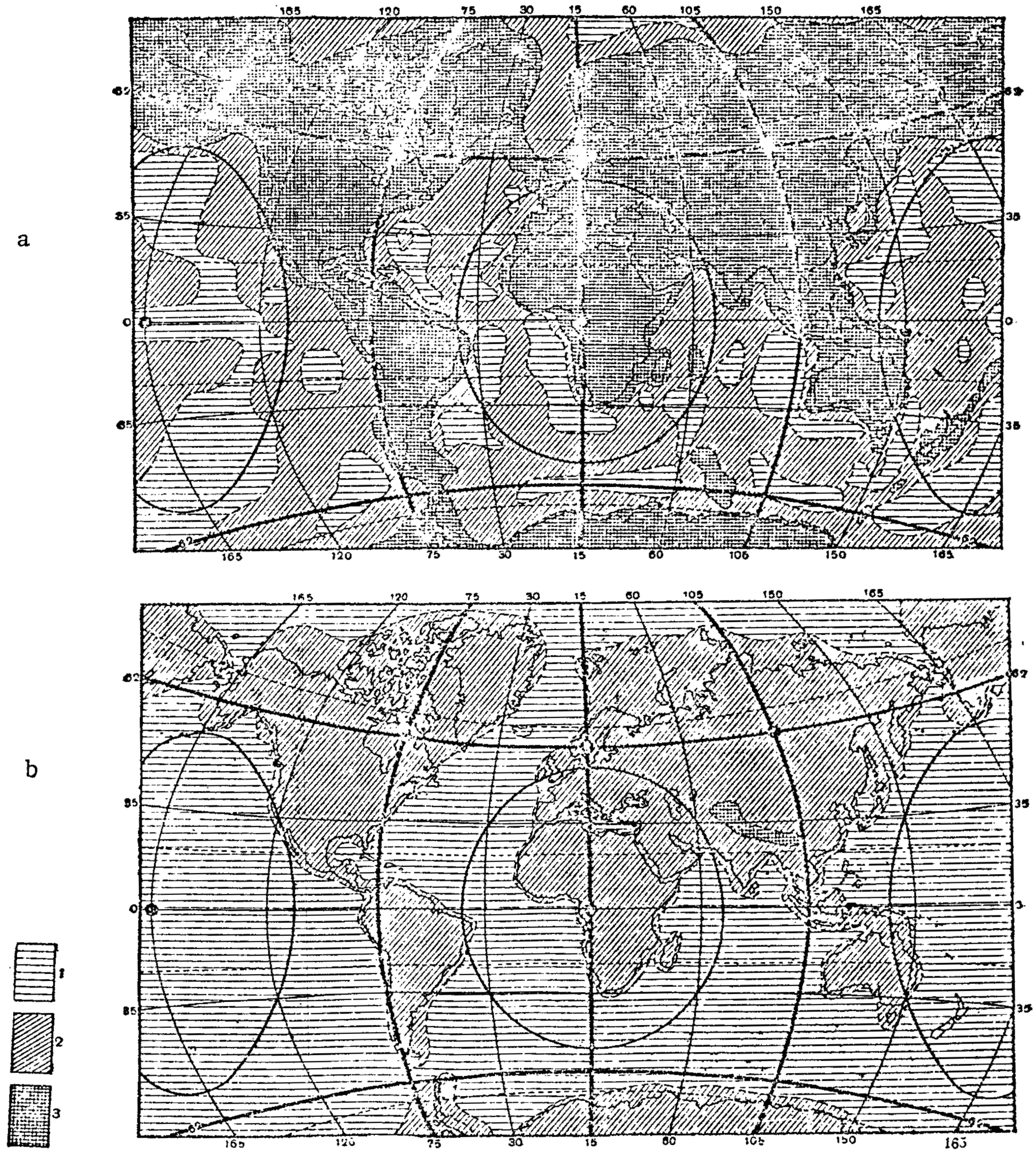


Figure 19. Geological Structure of the Earth's Crystalline Shell: a) at a Depth of 10 Kilometers, b) At a Depth of 30 Kilometers. (After R. M. Dementskaya, 1959, with the Addition of Active Circles and Centers).
1 - Hyperbasite, 2 - Basalt; 3 - Granite with Intrusion of Sedimentary and Metamorphic Rocks.

/66

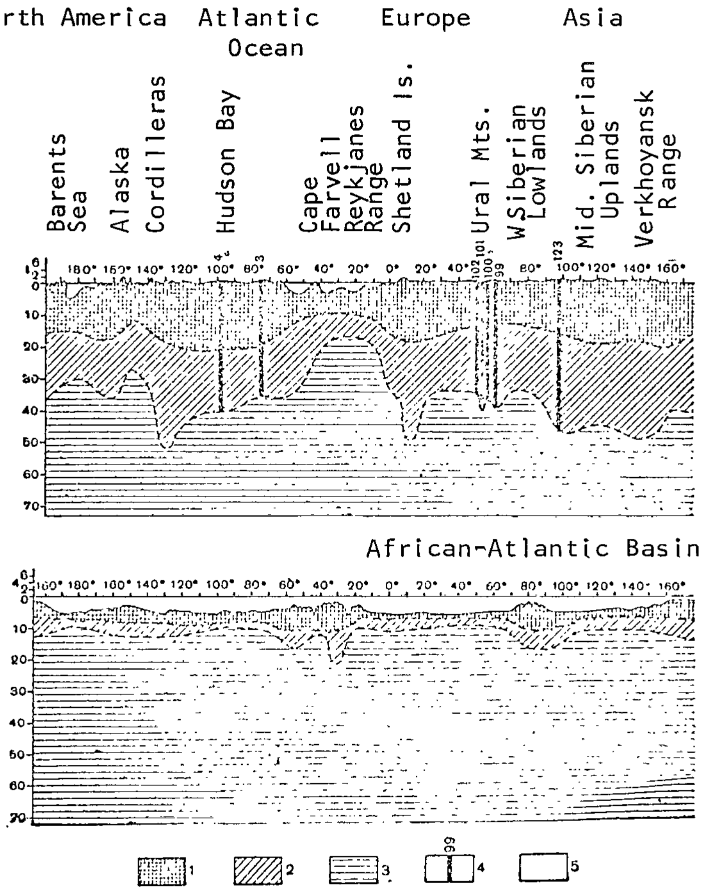


Fig. 20. Geological Structure of the Northern Continental Belt and the Floor of the Southern Ocean: a) at 60°N, Northern Continental Belt; b) at 60°S, Southern Ocean. (After R. M. Demenitskaya, 1959). Legend: 1 - Granite With Intrusion of Sedimentary and Metamorphic Rocks; 2 - Basalt; 3 - Hyperbasite; 4 - Position and Number of the Point Where the Section Was STudied by Seismic Methods; 5 - Water.

lithosphere of continents is evidently

$$2MgSiO_3 = Mg_2SiO_4 + SiO_2 + 2{,}3 \quad \text{kcal} \qquad (12)$$

clinoenstatite → forsterite + quartz + heat

Here the quartz, as the component of low density, will be carried

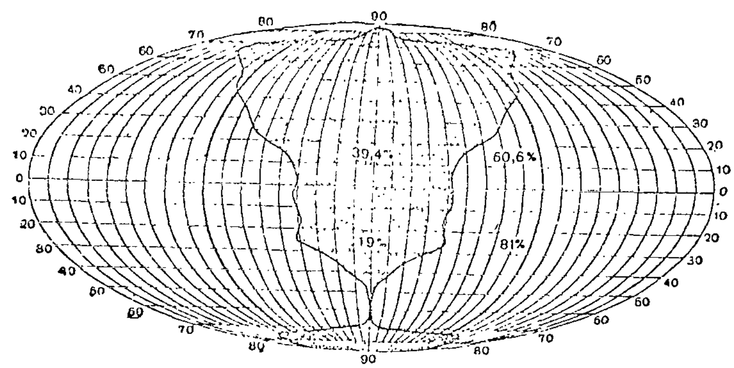


Fig. 21. Generalized Form of the Continents. Dry Land is Shown With Respect to the Total Area of Each 10-Degree Zone. The Meridians are Drawn at Intervals of 10°. Mollweide's Projection. (Compiled by Ya. Ya. Gakkel').

upward[1]. The reaction proceeds with an increase in volume, so that it is opposed by the forces of pressure. Feldspathic minerals also are formed with increase in volume, so that their formation is helped by reduction in pressure and hindered by increase in pressure. On the other hand, as F. Yu. Levinson-Lessing (1940) has pointed out, the minerals of ultrabasic rocks (as, for example, olivine, pyroxene, amphiboles) are formed with a reduction in volume, so that increased pressure favors their formation. Radial deforming forces arising during prolonged change in terrestrial compression within the critical parallels of ± 35° and ± 71°, in the Southern Hemisphere were directed along the radii of the parallels toward the axis of rotation, but in the Northern Hemisphere they were directed away from the axis (See Figure 8-b). Therefore, for all parallels between 35° and 71°, pressure forces are less in the Northern Hemisphere than at the corresponding parallels in the Southern Hemisphere. The difference rises from zero at the critical parallels as one approaches ± 62°. Therefore, the most favorable conditions for the formation /67
of silica and the feldspathic minerals are found, in the case of the Northern Hemisphere, in the zone of influence of the 62nd parallel, where pressure is lower; and, in the case of the Southern Hemisphere, also near the 62nd parallel, although here the pressure has been increased.

Of great significance is the fact that rocks laid down on the ocean floor have for a long time been under the steadily increasing pressure of the water, which today at some places reaches 1,000 atmospheres.

In connection with the fact that the physico-chemical process in question

[1] The process is actually much more complex. This is a simplified scheme which facilitates finding an explanation of why the rate of formation of the granitic lithosphere has differed in various zones of the planet.

is controlled by mechanical factors, the formation of the earth's lithosphere (its granitic-sedimentary and basaltic layers) and the deepening of the Mohorovivic discontinuity have proceeded unevenly--more slowly in some zones and more rapidly in others. Among the "slow" zones are those under the influence of the extremum parallel 62°S and the North Poles; among the "fast" zones are those under the influence of the extremum parallel 62°N and the South Pole. Therefore, the thickness of the lithosphere within the limits of the Southern Ocean and the Arctic polar basin is less than within the limits /68 of the northern continents and the Antarctic polar continent. Consequently, the parallel 62°N is epeirogenetic, and that of 62°S thalassogenetic, while the North and South Poles are, respectively, thalassogenetic and epeirogenetic.

Within the zones of influence of the circumpolar critical parallels (± 71°) there appear distinct regional dislocations and sublatitudinal fractures. In the Northern Hemisphere, these bound the polar ocean and the northern continents; in the Southern Hemisphere, the polar continent and the Southern Ocean.

Thus, secular downward movements and comparatively high pressure in the earth's shell in the temperate latitudes of the Southern Hemisphere, and upward movements and reduced pressure in the same latitudes of the Northern Hemisphere, have led not only to secular qualitative change in the composition of the rocks in the earth's antipodal zones, but also, as a consequence, to subsidence of the lithosphere in the Southern Hemisphere and uplift of the lithosphere in the Northern Hemisphere. In the polar zones of the earth we find an analogous situation: downward movements in the shell, the formation of simatic masses and secular subsidence of the lithosphere, in the case of the Arctic, and the formation of sialitic masses and secular uplift of the lithosphere in the case of the Antarctic.

Thus, in the space of 4 - 5 billion years, as a result of very complex processes of mechanical and physico-chemical interaction of the masses of the entire earth in a single, planet-wide tectonic development, the following phenomena arose: a greater thickness of the crust in continental regions as compared with oceanic regions; the oceanic character of the Southern and the continental character of the Northern Hemisphere; and the oceanic character of the northern polar region and the continental character of the southern polar region. All of these phenomena were interrelated by virtue of a common origin and structural development. We see here how weak forces, constantly acting in a single direction for an enormous period of time, may combine to produce a significant effect. In this connection, the distribution of polar dry land and seas with respect to the earth's axis of rotation reflects both the surface and the abyssal asymmetry of the earth's figure with respect to the equatorial plane.

Asymmetry of the Earth's Magnetic Field /69

It is a curious fact that not only the distribution of dry land and sea, but also the intensity of the earth's magnetic field, exhibits a definite asymmetry, in the sense that "...the mean intensity of magnetization for corresponding northern and southern parallels is usually greater for those parallels which lie predominantly on dry land than for those which lie mostly on the water" (L. A. Bauer, 1923, p. 24). In other words, the internal magnetic field is asymmetrical with respect to the geomagnetic equator, and, just like the figure of the earth, can be represented as a heart-shaped geometrical construction.

The Origin of the Great Ocean and Africa. The Formation of Circum-Pacific and Cricum-African Belts of Mountains and Fractures

As of 1950, the coordinates of the earth's magnetic poles were as follows: 72°N, 96° W and 70° S, 150° E. In this connection, it is noteworthy that the great circle formed by the meridian 28° E - 152° W, which is perpendicular to the plane on which the two magnetic poles are found, divides the dry-land area of the earth into two equal portions. The surface features of the earth are symmetrical with respect to this great circle, but extremely unsymmetrical with respect to the great circle which is perpendicular to it. The coordinates of the geomagnetic poles which correspond to the earth's field of homogeneous magnetization are 78°32' N, 69°08' W and 78°32' S, 110°52' E. The great circle formed by the meridian 21° E - 159° W, which is perpendicular to the projection of the geomagnetic axis on the equatorial plane, is remarkable in that it coincides with the meridional line marking the extremity of Africa and the Great (Pacific) Ocean (Figure 22). In their turn, these two remarkable circles very nearly coincide with the meridians of the major equatorial axis (15° E - 165° W), the meridians of the minor nutational axis (12° E - 168° W), and the axis of minimal variations in sea level and atmospheric pressure (0 - 180°). A whole series of surprising coincidences.' But surprising only at first glance: in reality all these phenomena are physically interconnected.

The plane of the minor equatorial axis (105° E - 75° W) divides the /71
terrestrial ellipsoid into two hemispheres, with one pole in the Great Ocean and the other in Africa--the "Pacific Hemisphere" and the "African Hemisphere". Africa is the continent which counterbalances the Great Ocean--both are very ancient structures. But Africa and the Great Ocean are antipodal not merely in the geometrical sense: they are also antipodal as regards development. Africa is the continent with the greatest tendency to uplift, as is shown by its quite weak complement of youthful sedimentary rocks. The Great Ocean, on the other hand, is characterized by intensive volcanic activity, abyssal fractures, and deep-focus earthquakes on its borders--all signs of a subsiding basin. The floor of this ocean is entirely without any sialitic layer.

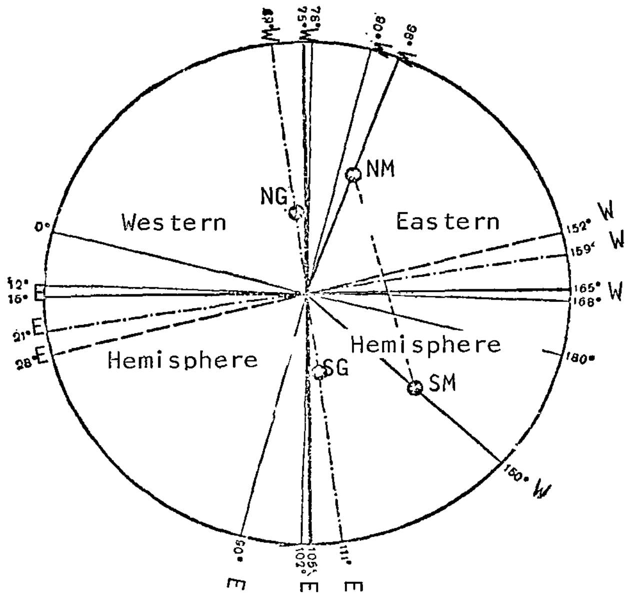


Fig. 22. Interrelationship Between the Various Physical Fields of the Earth.

105 - 75°: Meridian of the Minor Equatorial Axis of the Terrestrial Ellipsoid (After A. A. Izotov, 1950);

102 - 78°: Meridian of the Major Axis of the Nutational Ellipse (After A. Ya. Orlov, 1944);

90 - 90°: Meridian of the Axis of Maximal Fluctuations of Sea Level and Atmospheric Pressure (After I.V. Maksimov, 1952);

111 - 69°: Meridian of Projection of the Geomagnetic Axis on the Equatorial Plane;

15 - 165°: Meridian of the Major Equatorial Axis of the Terrestrial Ellipsoid;

12 - 168°: Meridian of the Minor Axis of the Nutational Ellipse;

0 - 180°: Meridian of the Axis of Minimal Fluctuations of Sea Level and Atmospheric Pressure;

21 - 159°: Meridian of a Line Perpendicular to the Projection of the Geomagnetic Axis on the Equatorial Plane;

21 - 159°: Meridian of the Line of Greatest Extension of Africa, Europe and the Great Ocean,

28 - 152°: Meridian Bisecting the Earth's Dry-Land Area; the dry-land areas on both sides of the meridian are equal;

28 - 152°: Meridian of the Point of Intersection of the Magnetic Axis with the equatorial plane:

Coordinates of the Magnetic Poles (as of 1950):

NM - 72°N, 96°W; SM - 70°S, 150°E.

NM - SM Projection of the Magnetic Axis on the Equatorial Plane.

Coordinates of the Geomagnetic Poles:

NG - 78°32' N, 69°08' W; SG - 78°32' S, 110°52' E.

NG - SG: Projection of the Geomagnetic Axis on the Equatorial Plane.

The shield-shaped uplift of the whole of Africa and the sinking of the floor of the Great Ocean--in fairly recent times--are evidenced by numerous geological data (Kh. Stirns, 1945; P. N. Kropotkin, 1948; V. V. Belousov, 1955, N. I. Nikolayev, 1955; etc.) The rate of subsidence of the ocean floor, as estimated by F. Kyunen (1955), is about 20 meters per million years. The uplifts of the African continent have been compensated by subsidences along the borders of the continent, near the Indian and Atlantic Oceans, as well as by subsidences of the Great Ocean, and by uplifts along the border of the Great Ocean, in America and Australasia.

The formation of Africa and the Great Ocean, which are antipodes, is closely tied in with the asymmetry of the structure of the two hemispheres. The earth's greatest oceanic trough is rimmed by a mighty "circle of fire"--the Pacific ring of mountains, volcanoes and superabyssal (down to 700 kilometers) fractures. The Pacific ring of superabyssal fractures and earthquakes is genetically associated with the ocean; probably it was already established in the early Archean, along with the ocean itself. The ring is antipodal to the more weakly developed Circum-African belt of mountains, fractures and earthquakes. Consequently, we see here two systems of varied /72
antipodal and asymmetrical phenomena, whose development has been interdependent. This demonstrates that the relief and structure of the earth are substantially asymmetrical not only with respect to the equatorial plane, but also with respect to the plane defined by the meridian of the minor equatorial axis (105° E - 75° W).

What has caused the asymmetry of the earth's structure and relief in this second instance? In the chapter on the causes of tectonic movements, we demonstrated that the basic difference in the development of the oceanic (Pacific) and continental (African) hemispheres, and particularly the genesis of the Great Ocean and Africa, is associated with the pregeological history of the Earth-Luna double planet--more precisely with the moon-induced asymmetry of the figure of the earth with respect to the plane defined by the meridian of the minor equatorial axis. Something, however, remains to be added to this argument.

According to the theory of G. H. Darwin, which was widely held in the late 19th and early 20th centuries, the moon was created from a "rib" of the earth. W. H. Pickering (1907) thought that this "rib" had come from the site of the present-day Great Ocean. But both Darwin's theory and Pickering's hypothesis based on it for explaining the origin of the Great Ocean proved to be just as inadequate as the Biblical myth about Eve being created out of Adam's rib.

We have already discussed the astronomical objections to this idea of Darwin and Pickering. But there are geological objections as well:

1. The density of the lunar substance amounts to 3.33 gr/cm^3--in other words, it is quite different from that of the sial(2.82 g/cm^3) from which Pickering thought it was formed, but about the same as that of the density

of the "peridotite" shell of the earth;

2. The "wound" which, according to Darwin's theory, was formed when the moon was torn away from the liquid planet, must have "healed over" pretty quickly, in view of the low viscosity of fused silicates; it would have been filled in and covered over by an influx of substance from other, undamaged portions of the sialic layer,

3. Pickering's hypothesis is quite insufficient to explain the rise of the Atlantic and Indian Oceans, which have very nearly the same structure and composition as does the Great Ocean (P. N. Kropotkin, 1950); /73

4. Pickering's hypothesis fails to explain the antipodal relationship between Africa and the Pacific Ocean, the formation of which could not have been independent, and

5. Pickering's hypothesis offers no explanation of the origin of the Circum-Pacific mountain belt, which cannot be viewed in isolation from that of the Pacific itself[1].

Since there could have been no tearing away of the moon from the earth, then obviously the two planets never formed a single body. Consequently, the initial proximity of the moon to the earth can be explained not as a separation, but as the contemporaneous formation of the two bodies in close proximity, within the primordial cloud of gas and dust from which all the other planets were formed[2]

[1] In criticizing Pickering's hypothesis, we must not fail to see that it contains an important element of truth--namely, the idea of a genetic connection between the Pacific Ocean and the moon.
The Pacific Ocean is a unique planetary formation. It occupies nearly a third of the terrestrial surface, and has (if one may use the term) a segmental distribution. On no other planet is there observed a depression so massive as the Pacific, or situated in the same way; and at the same time no other planet has a satellite so relatively large as our moon.

[2] Even after work on the present volume had been completed, Ye. L. Ruskol (1960) pointed out that, as a result of inelastic collisions between small bodies close to the growing earth, a "satellite swarm" must have been formed around our planet, consisting of small solid bodies. The material of this swarm served as the raw material for the formation of the moon, by a mechanism consisting of the capture and subsequent consolidation of individual small bodies. The probability of such capture would have been maximal close to the earth, but close to zero at a point distant from the earth. Therefore, the concentration of material in the swarm would be maximal in portions nearest the earth. From this it follows that the moon, most probably, was formed somewhere within the limits of 2.5 to 10 earth radii.

It is a point of interest that the formation and subsequent dissociation of the moon from the earth directly preceded the formation of the earth's crust (See Figure 12). This was no mere coincidence, but rather a direct causal relationship between two highly significant events in the earth's history.

Following the formation of the core, the lithosphere, the hydrosphere, and the other shells of the earth, the subsequent development of the planet can be outlined in the following fashion:

As a result of the leveling of the east-west asymmetry, erosion of the continental hemisphere, and removal of the eroded material into the basin of the Pacific Ocean, and also as a result of the subsidence of the Pacific Ocean floor under the influence of isostasy, additional pressure was placed upon the earth's core (See Figure 14). This pressure served to maintain the process of forming a terrestrial bulge in the antipodal (African) portion of the continental hemisphere. During the Mesozoic era, this process was joined by compensating subsidences of the lithosphere east and west of Africa, these were associated with the movement of subcrustal material within the areas of the Indian and Atlantic Oceans. This is attested by the presence of continental structures which have subsided significantly below sea level, but strike along the Indian and Atlantic peripheries of the African continent. /74

It may be assumed that not only the formation of the Atlantic and Indian Oceans, but also that of the Mediterranean Sea, are associated with the formation and uplift of the African continent: the latter phenomenon, in its turn, brought about a prolonged subsidence of Pacific Ocean trough, as we have just seen.

Thus, the pregeological development of the earth affords a clue to the planet's geological development. Africa and the Pacific Ocean can be regarded as two enormous and continuously changing "birthmarks" on the face of our planet. With the formation and development of these two antipodal megastructures are closely associated still other planetary tectonic forms-the Circum-African mountain belts and Karpinskiy's meridional belt.

The Origin of the Antipodal Character of the Eastern and Western Continents

As was demonstrated as early as 1859 by the Russian geodicist F. F. Shubert, the terrestrial equator is not a circle, but rather, in first approximation, an ellipse. *The ellipticity of the earth in equatorial cross-section*--or, as one might say, the earth's triaxiality--*and the east-west asymmetry of the figure of the earth, have a common origin. Here we are dealing with two facets of the same phenomenon, cosmogonically conditioned by the asymmetrical-triaxial distribution of masses within the body of the planet.* /75

African Hempisphere

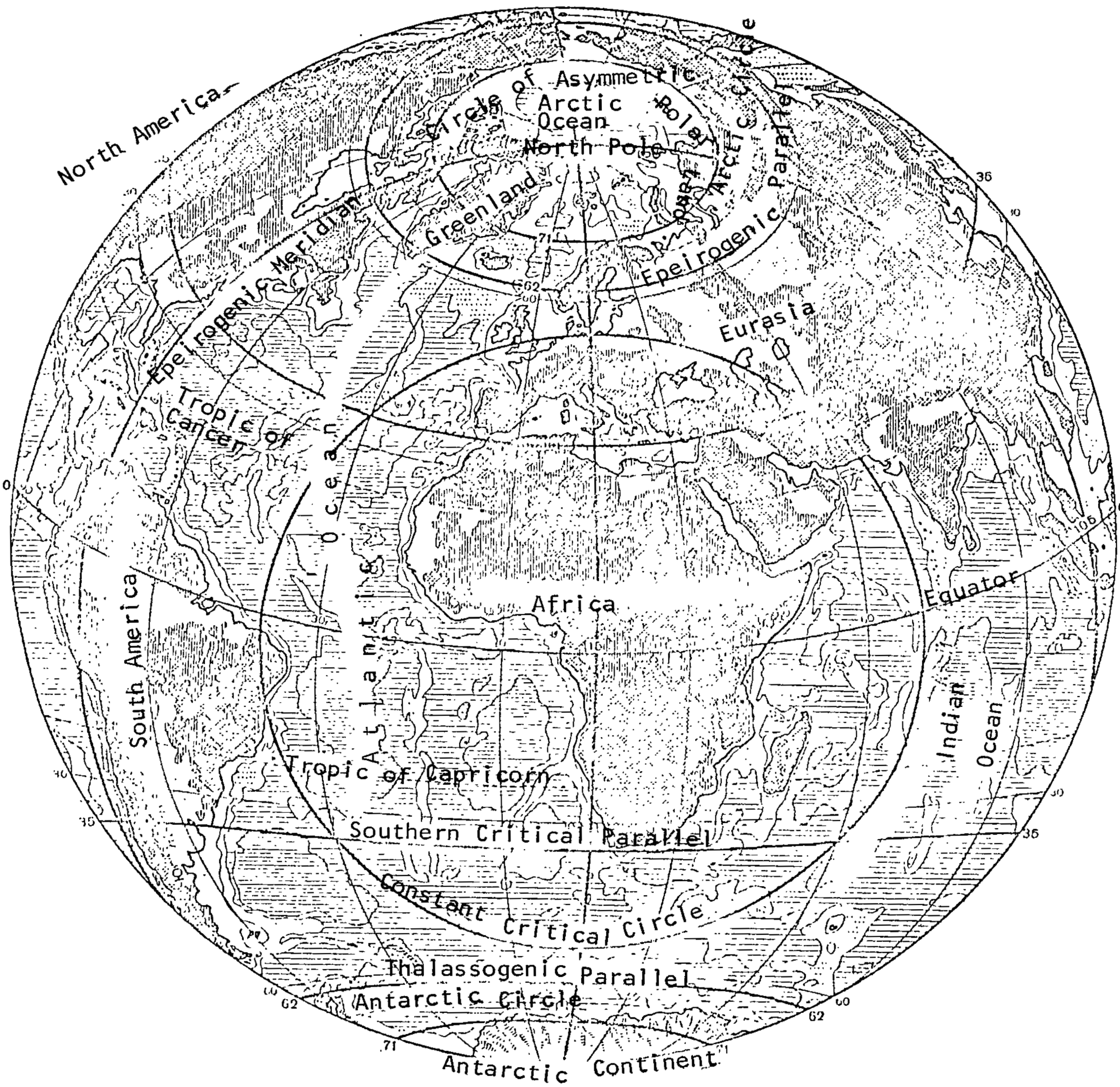
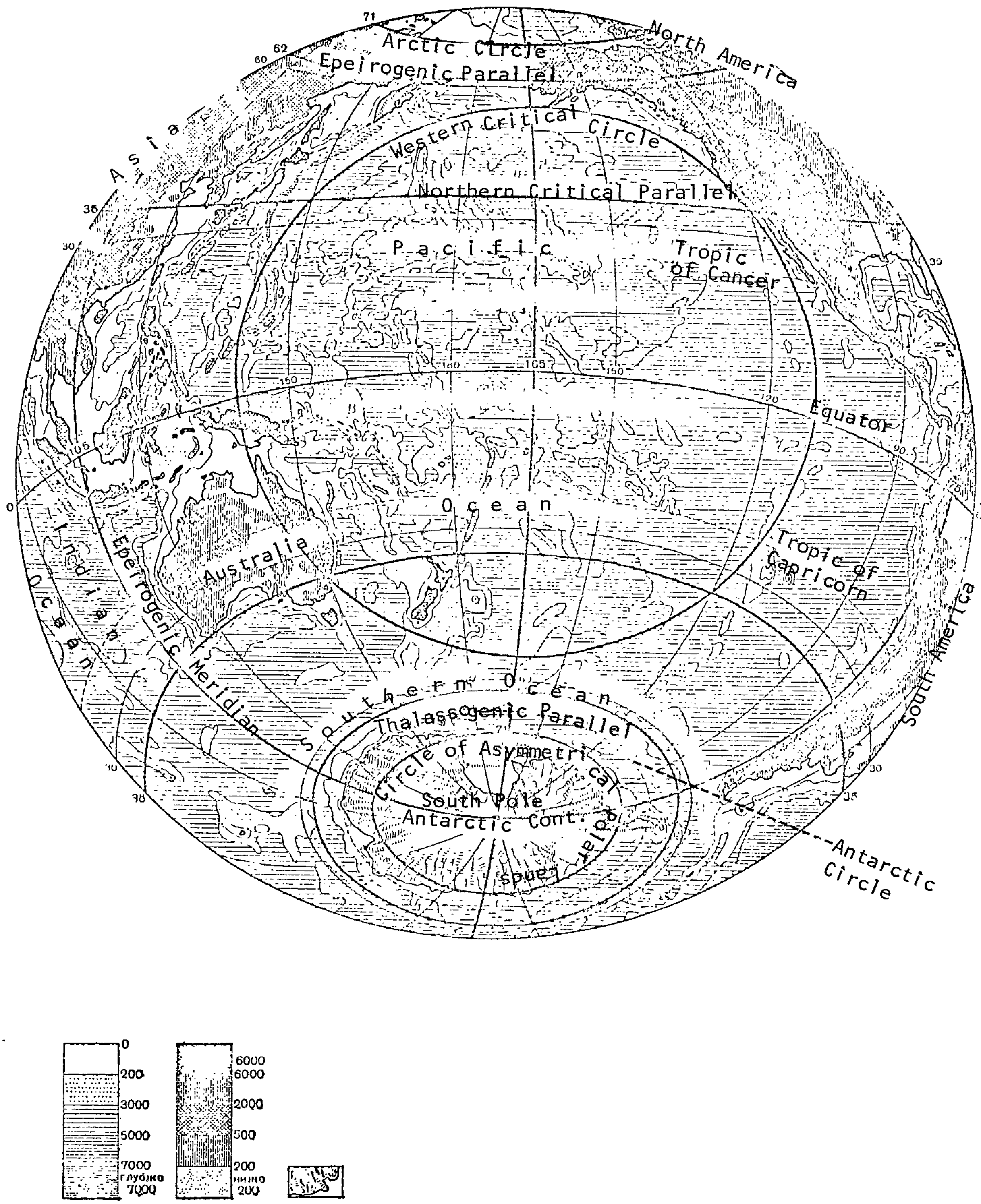


Fig. 23. Relief and Active Circles of the Terrestrial Ellipsoid.

The scale on the left shows depths in meters, that on the right heights in meters. The marking at the extreme right denotes ice cover.



Arctic Circle
Epeirogenic Parallel
North America
Asia
Western Critical Circle
Northern Critical Parallel
Pacific
Tropic of Cancer
Equator
Ocean
Tropic of Capricorn
Australia
Indian Ocean
Epeirogenic Meridian
South America
Southern Ocean
Thalassogenic Parallel
Circle of Asymmetrical
South Pole
Antarctic Cont.
polar
Lands
Antarctic Circle
0
200
3000
5000
7000
глубже 7000
6000
6000
2000
500
200
ниже 200

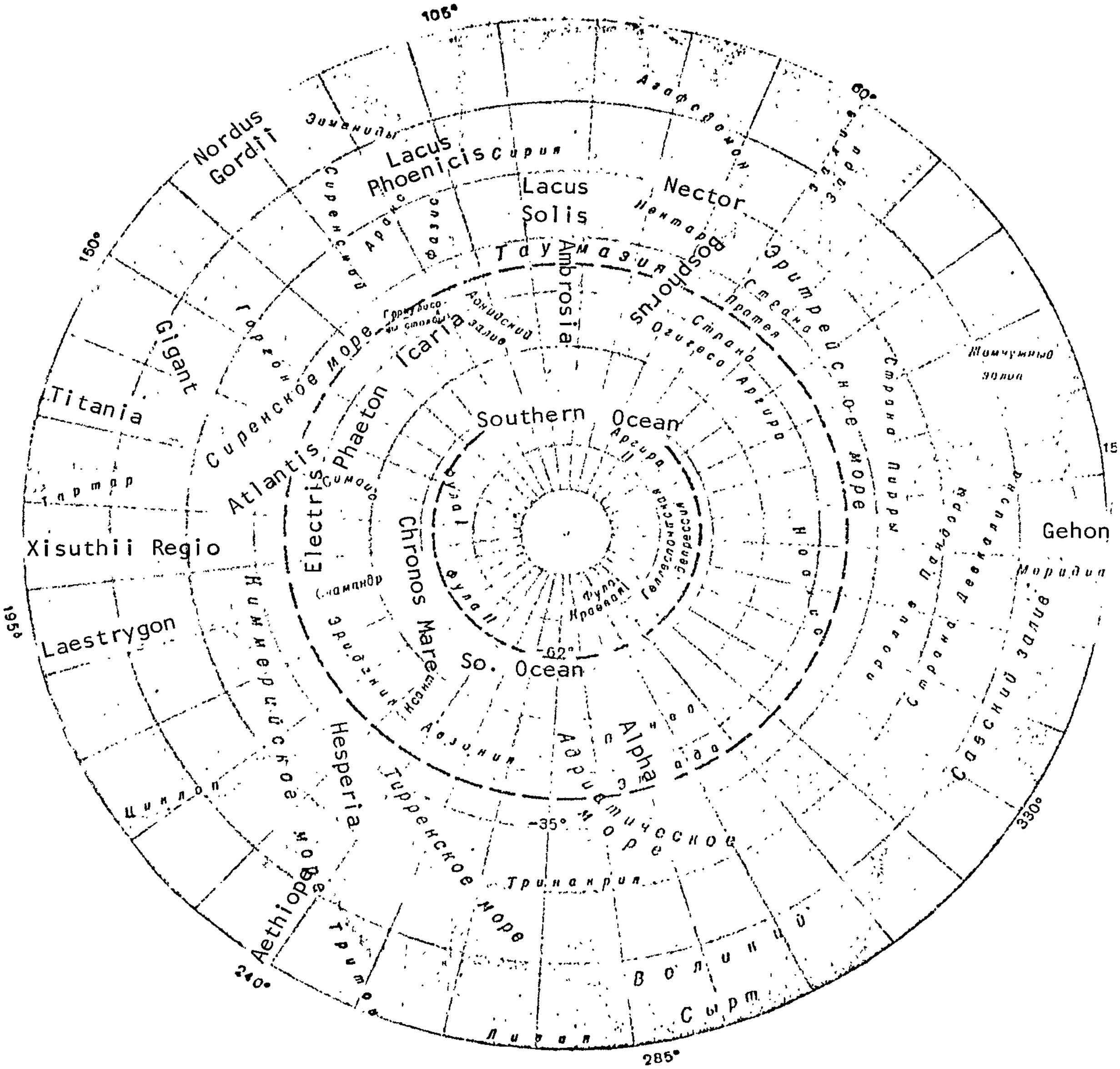


Fig. 24. Surface Features of Mars, as Based on Schiaparelli's Observations of 1879.

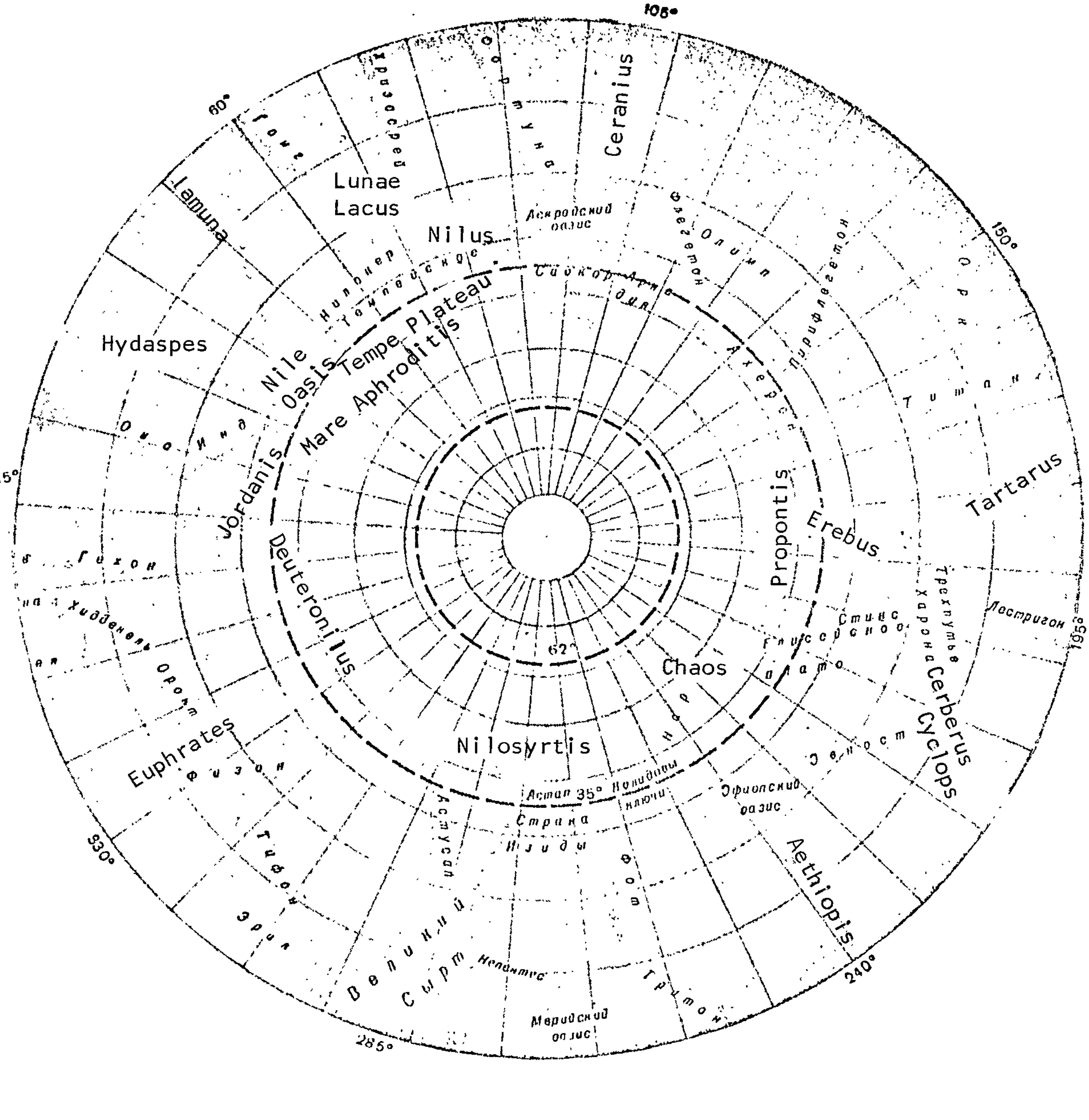


Fig. 24 (Concluded)

The longitude of the major equatorial axis, according to A. A. Izotov (1950), is 15° E (Greenwich).

All of the continents, apart from Africa and the southwestern part of Europe, are disposed in the direction of the meridian of the minor equatorial axis: 105° E, 75° W (See Figure 17). Asia and Australia are found on one side of the terrestrial ellipsoid, the two Americas on the opposite side. The antipodal sectors of the major equatorial axis (15° E, 165° W) are occupied by the Pacific Ocean, on the one side, and in part by the Atlantic and Indian Oceans, on the other. As we have seen, these structures are interdependent, on the basis of the following causal scheme: subsidence of the Pacific Ocean floor ---→ shield-shaped uplift of Africa ---→ subsidence of portions of the Indian and Atlantic Ocean floors adjacent to Africa ---→ uplift of Africa.

But since these tectonic movements, together with the physico-chemical changes accompanying them, condition the character of the rise of terrestrial structures, the connection symbolized above can be expressed even more succinctly: Pacific Ocean ---→ Africa $\rightleftarrows$ Indian and Atlantic Oceans (partially).

A slow tangential movement (continuing up to the present time) has occurred in the subcrustal material, from the segments of the Pacific Ocean, and in lesser degree from those of Africa, through the belts of influence of the western and eastern critical circles into the belt of influence of the meridian of the minor equatorial axis. These shifts (or strivings toward the same) have been caused by stresses associated with the tendency of the earth to "eliminate" its triaxial-asymmetrical deviations from the proper form of a spheroid. Therefore, we find oceanic subsidences associated with the Pacific Ocean segment and with the African segment, and the formation of continents associated with the belt of influence of the epeirogenetic meridian of the minor equatorial axis.

The genetic link between Karpinskiy's continental belt and the epeirogenetic meridian (105° - 75°), and the antipodal positioning of Africa and the Pacific Ocean, are very evident on the accompanying map (Figure 25).

The projection used in the map (Figure 25), which is of cylindrical type, /77 is of interest in its own right. It is superior to other projections in that it involves no distortion of the areas or the contours of the continents, while preserving their essential form and correct relative positioning on the planet.

At this point some additional interesting patterns become evident: along the meridian of the major equatorial axis we observe the greatest protrusion of the Arctic Ocean, and the least protrusion of the Antarctic Continent, while the direction of the meridian of the minor equatorial axis coincides with the maximal meridional protrusion of the continents of Eurasia, America and Antarctica. Possibly the unevenness of the opposite equatorial semiaxes

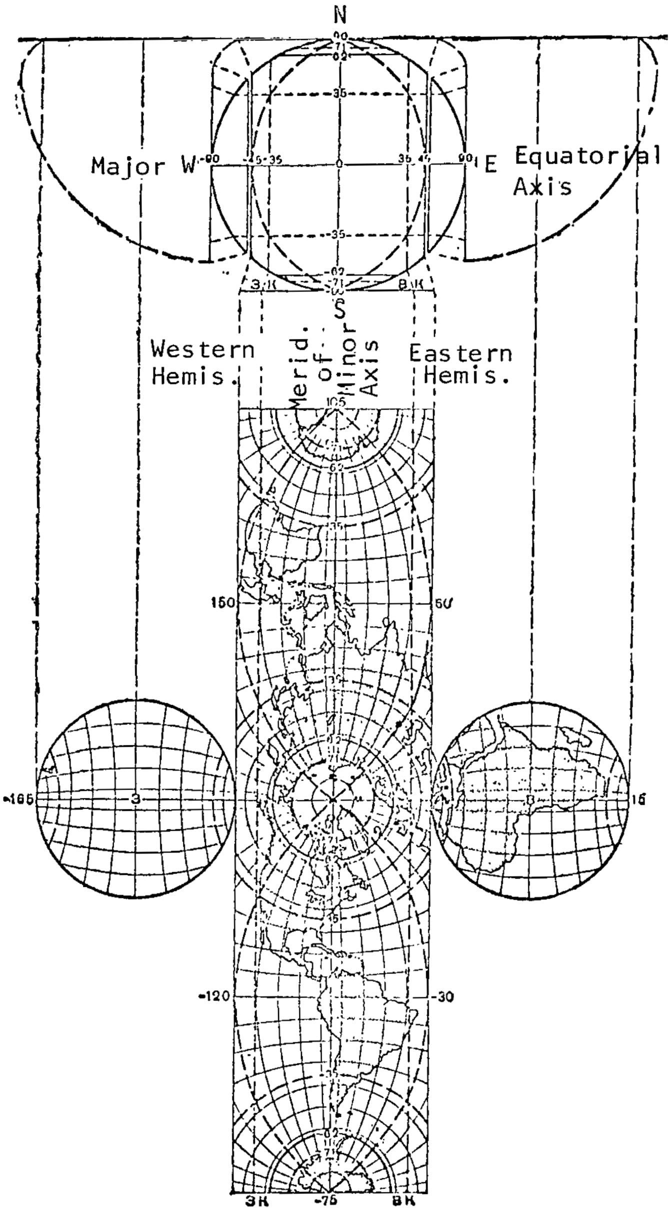


Fig. 25. Distribution of the Continents With Respect to the Meridian of the Minor Equatorial Axis. The Heavy Solid Lines Denote the Western and Eastern Critical Circles, the Critical Parallels (±35°), and the Critical Meridians (60 - 120°, 150 - 30°).

Note: Angular Distances of the Active Meridians are Given as Follows: Upward, From the Meridian of the Minor Equatorial Axis; Downward, From the Meridian of Greenwich.

explains the fact that the eastern part of Antarctica is larger than the western.

It is clear, from all that has been said, that the antipodal character of Australasia and the two Americas has been conditioned by tectonic movements resulting from a tendency of the asymmetrical-triaxial ellipsoid to assume the more stable configuration of a cardioidal ellipsoid of rotation.

The Wedge Shape of Continents and Oceans. Parity of Links Between Northern and Southern Continents. The Smaller Area of Southern Continents.

The third characteristic surface feature of the earth (arising from the first two) is *the wedge-shaped outline of every continental mass*[1]. Since the wedge-shaped form of the southern extremities of the continents is a consequence of the first two homologies, it follows that the third must be associated with the rotation of the planet. /78 The tectonic movements forming the Karpinskiy continental belt (mean longitude 105° - 285°) in the temperate latitudes of the Northern Hemisphere interacted with other tectonic movements (identical in sign) which formed the great northern belt of continents. As a result of the superimposition of one set of tectonic movements upon the other, we find within modern Canada and Siberia the so-called "continental shields" which arose in early Archean times--portions of the lithosphere with the most stable tendency to uplift. The traces of these uplifts can be observed on the shore of the Arctic Ocean, in the form of ancient marine terraces raised high above sea level. These movements are characteristic not only of the distant and recent past, but also of the present epoch. The area of the Canadian Archipelago, for example, is continuing to increase, at the expense of uplift of the ocean floor, and as a result new islands are appearing.

L. S. Berg (1955) believes that as a result of these vertical uplifts, the table mountains of the Central Siberian Highlands have risen to altitudes 3 - 5 times as high as the mean altitude of the region (200 - 400 meters).

The Canadian and Siberian continental shields represent the primeval nuclei of the modern continents of North America and Asia; they are in fact the centers of formation of those continents (See Conclusion, Figures 31 and 33). These nuclei have been "overgrown" with new, subsidiary portions of dry land, and there has been a progressive increase in the area of the continents: these processes have taken place mainly in two directions--the southwesterly, along the epeirogenic parallel of 62° N, and the meridional, along the epeirogenic circle of 105° - 75°. It is therefore no accident that the 62nd parallel is the circle of the greatest zonal extension of the continents, while the meridian 105° - 75° marks the greatest meridional extension (Figure 25). The surface occupied by dry land diminishes on both sides of these main epeirogenic circles, while the wedge-shaped extremities of North America and Eurasia, as we have already seen, were formed as the

[1] It was Francis Bacon who first called attention to this homology (1620).

result of subsidence of the lithosphere of the equatorial belt resulting from secular decrease in polar compression.

In the Southern Hemisphere, the meridional belt of continents continues /79 in the form of South America and Australia. Whereas the northern continents (North America and Asia) were formed by zonal and meridional uplifts, the southern continents (South America and Australia) were placed in the equatorial zone of the general secular subsidence of the lithosphere. Precisely for this reason the area of the southern continents is smaller than that of the northern.

The "thinning out" of South America, Australia and Africa toward the south is associated with the gradual increase in subsidence of the lithosphere from the critical 35° S parallel to the 62° thalassogenic parallel. Africa and Australia fade out completely in the vicinity of 35° S, and only South America persists south of that latitude:

Cape Agulhas in Africa...........34°52' S
Cape Wilson in Australia.........39°11' S
Cape Horn in South America.......55°59' S

As regards the thinning out of the continents in the direction toward the meridian of the maximum equatorial radius (Chukotka in Asia and Alaska in North America), we can attribute this phenomenon to subsidence of the lithosphere of the Pacific sector.

In the Atlantic and Indian sectors we find analogous causes of the wedge-shaped external form of Labrador in North America, Bahia in South America, and Somali in Africa.

Thus, the common, oppositely-directed "wedge quality" of oceans and continents, and also the thinning out of the continents near the equator and in the longitudinal direction, are phenomena inherently associated with axial rotation and with the past history of the earth as part of the Earth-Luna system. Not only tectonic processes (downward movements of the ocean floor and upward movements of the continents) but also geochemical differentiation of the terrestrial substance (creating rocks of various content which went to form the continents and ocean floor) participated.

Let us construct a generalized profile of Australasia and America, taking into account the following: 1) secular meridional uplifts and "granitization"[1] of the lithosphere, increasing from the eastern and western critical /81 circles toward the epeirogenetic meridian of the minor equatorial axis (105° - 75°); 2) secular zonal subsidences and "oceanization" of the lithosphere, diminishing from the thalassogenetic parallel (62° S) toward the

[1] "Granitization" of the lithosphere results not only from internal abyssal processes (accumulation of materials at lower levels), but also from external ones (physico-chemical weathering of the earth's crust).

equator, and also secular zonal uplifts of the lithosphere, and the influx of sialic and granitic intrusions, increasing toward the epeirogenetic parallel (62° N); and, finally, 3) secular subsidences of the lithosphere, abyssal outflow of sialic material, and basaltic eruptions within the limits of the equatorial belt between the critical parallels (± 35°), increasing from those parallels toward the equator. As a result of the accumulation of the deformations referred to, we arrive not only at the third, but also at the fourth and fifth homologies associated with it--namely, *the parity of junctions between the northern and southern continents, and the smaller area of the southern continents in comparison with the northern* (Figure 26).

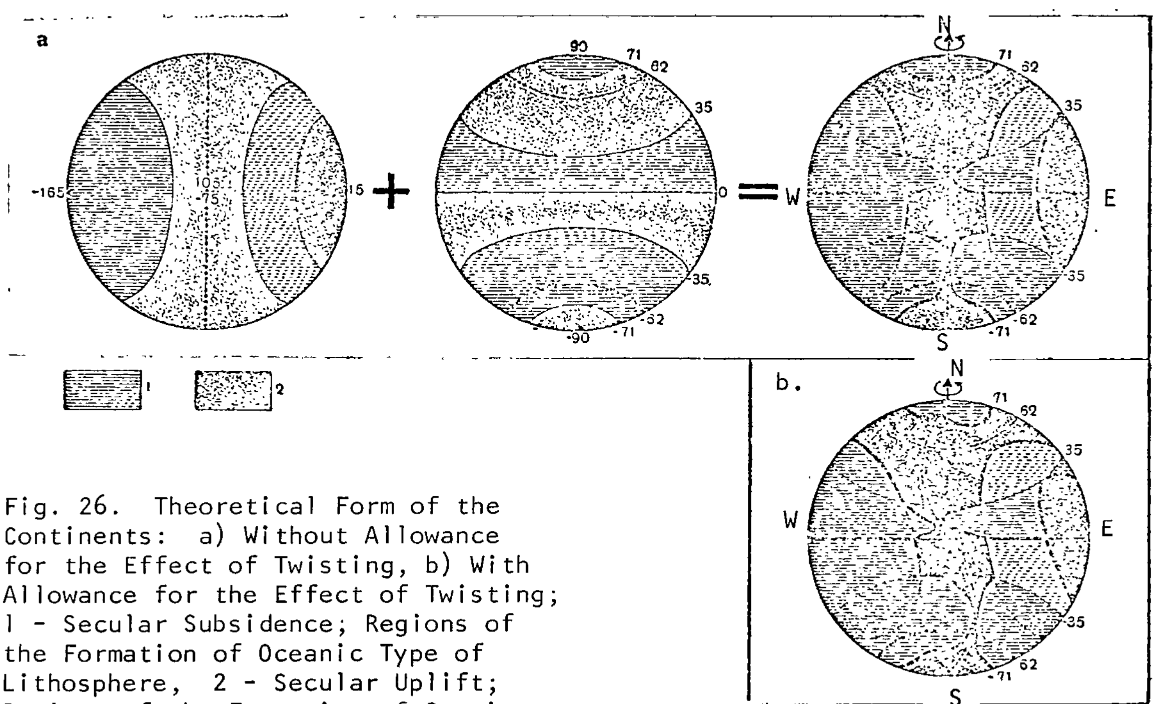


Fig. 26. Theoretical Form of the Continents: a) Without Allowance for the Effect of Twisting, b) With Allowance for the Effect of Twisting; 1 - Secular Subsidence; Regions of the Formation of Oceanic Type of Lithosphere, 2 - Secular Uplift; Regions of the Formation of Continental Type of Lithosphere.

Relative Displacement of Northern and Southern Continents, and Certain Other Consequences of the Twisting Effect

A glance at the map reveals that South America has been displaced to the east of the minor equatorial axis, and North America to the west of it. Australia has been displaced to the east more than the other continents, but even in the case of Africa, the equatorial continent, we detect a slight, but very real, relative displacement with respect to its north-south axis. These parallel displacements are the principal cause of the parallelism of the shorelines of the continents (See also Figure 27). In particular, the

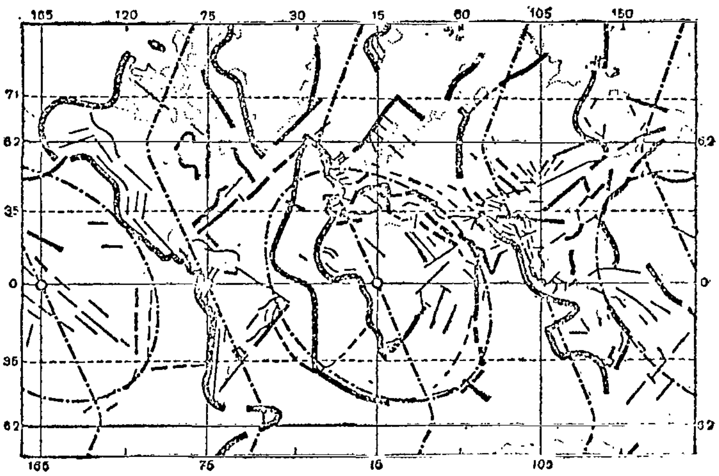


Fig. 27. Axes of the Continents and Oceans, Fractures of the Earth's Crust, and Parallel Shorelines of the Continents in Connection With the Effect of Twisting of the Earth's Surface Around the Axis of Rotation.

parallelism of the two shores of the Atlantic was first pointed out by our national colleague Ye. V. Bykhanov in 1877, and later on in 1915 by the German /82 geophysicist A. Wegener. Both Wegener and Bykhanov explained this phenomenon as the removal of both the Americas from Europe-Africa toward the west--as a displacement of sialic materials with respect to the plastic-viscous sima, under the effect of terrestrial rotation.

But these views turned out to be untenable. In 1944 the American geologist Bailey Willis devoted an article to the Wegener theory of horizontal displacements of the continents which he entitled "Continental Drift--*ein Märchen*". One cannot do better than adopt this brief but expressive aphorism, for in the light of modern scientific data the movement of the continents as Wegener understood it is indeed nothing more than a fantasy. However, it would be wrong to conclude from this that, in general, any sort of movement of the continental masses is impossible.

The displacement of the southern continents toward the east, with respect to the northern continenets, of which they are the continuation, is closely associated with the formation of the oceanic quality of the earth's Southern Hemisphere, and the continental quality of its Northern Hemisphere. The northern continents are displaced toward the west as a result of the uplift of the Northern Hemisphere, just as the Southern continents are displaced toward the east as a result of the subsidence of the lithosphere of the Southern Hemisphere. In proportion as the cardioidal form of the earth became more pronounced, the lithosphere of the Northern Hemisphere, from the equator as far north as the critical parallel of 71° N, moved off from the earth's axis of rotation, and at the same time the lithosphere of the Southern Hemisphere (within the corresponding latitudinal limits) approached more closely to the axis. *The horizontal relative displacements of the continental masses of the two hemispheres were the result of these radial movements, and were directed tangentially toward the parallels--toward the west in the Northern Hemisphere, and toward the east in the Southern Hemisphere.*

Theoretically we should expect that displacements of the northern and southern continental masses would be equal to zero at the equator, and increase in proportion to latitude, achieving a maximum at 62° N and S (Figure 16). The world map shows that the theory is entirely justified, being in complete accordance with the data of observation. The presence of such a law is particularly evident in the "break" of the meridional axes of /83 America, Australasia and the Mid-Atlantic Ridge near the equator, in the sharp bend and eastward deviation of the southern extremity of South America and the northern extremity of Antarctica (Graham Land), and also in the formation of the South Antilles mountain arch.

As a result of the twisting of the terrestrial surface around the axis of rotation, the entire system of meridional and submeridional active circles has been deformed into an S-shape, while the direction of the greatest protrusion of Africa, Australasia, the Pacific Ocean, and the various local structures subordinate to them deviates from the meridional toward the northwest (Figure 27). The universal predominance of northwest strike, associated both with the effect of twisting and with the influence of submeridional critical circles, is observed, in particular, throughout the enormous expanse of Eurasia and North America west of the epeirogenic meridian 105° - 75°. The Eastern Sayan Mountains, the Altay Mountains, the Central /84 Kazakhstan Anteclise, the Western T'ien-Shan, the Himalayas, the Kopet Dag Range, the Donets Ridge, the Voronezh Anteclise, the Belorussian Anteclise, the Pay-Khoy Range, the Timan Ridge, the Eastern Carpathians, the Dinaric Alps, the Apennines, the Cordilleras of North America--these are only some of the most prominent examples. The floor of the central portion of the Pacific Ocean is literally sown with extinct and buried volcanoes. All of these, whether submarine or above sea level, combine to form linear ridges *which run predominantly in a northwesterly direction,* thereby clearly reflecting their dependence upon abyssal fractures formed as the result of the effect of twisting which supplied an outlet for volcanic eruptions.

This important law, of planetary significance, is evidenced in structures of the most varied age and scale. Since the time of G. H. Darwin (1879) it has represented an enigma, and before now no theoretical explanation was advanced for it.

Turning our attention now to the polar regions (the Arctic Ocean and Antarctica), we see that *they "rotate" in opposite directions--the Arctic toward the west, the Antarctic toward the east.* Both the trans-Polar and the more local block structures of these regions are subject to this "rotation": Lomonosov Range, Novaya Zemlya, the meridional sector of grabens and block mountains discerned by P. S. Voronov in 1959 which runs under the Antarctic ice from Prydz Bay to Amundsen Sea, the young mountain ridges of Western Antarctica, and so forth.

Varying Degrees of Dissection of the Shores of the Pacific, Atlantic and Indian Oceans. The Pacific and Indo-Atlantic Types of Shore

The degree of dissection of ocean shores is very uneven. Nevertheless,

even here it is possible to establish a connection with the movement of the moon around the earth and with the formation of the Pacific Ocean. Glancing over the world map from east to west, one observes a curious pattern: the western shores of the Pacific, Indian and Atlantic Oceans are dissected and dismembered more strongly than the eastern ones. Since tidal waves are /85
propagated along the earth's surface from east to west, we know that such waves are highest on the western shores and lowest on the eastern. Therefore, both the magnitude and the amplitude of the variable hydrostatic load on the eastern shore of a continent are greater than those affecting the western shore, and this explains the greater degree of dissection found in the former. But the strong dissection of a shore line, especially following the formation of narrowing bays or straits, tends to raise the height of tidal waves. This is precisely why very high tidal waves (up to 16.2 meters at syzygy) occur at the Bay of Fundy on the Atlantic coast of Canada. In the Pacific the greatest wave amplitude is found on the eastern shores of Asia, where it may exceed 11 meters in places.

The degree of dissection of ocean shores also is directly dependent upon the relative position of the shore line and any linear structures present (mountain uplifts and tectonic fractures). In regions where the direction of the shore coincides with the basic tectonic lines, the dissection is minimal--an example is the shore of the Pacific, which strikes parallel to the structures of the Pacific circular belt of mountains and superabyssal fractures. Wherever the shore cuts across the tectonic structures, either at an angle or perpendicularly, one finds strong dissection: this happens in the case of the Atlantic shore of the two Americas, Europe and Africa, and the Indian shore of Africa, Arabia, India and Australia. Of interest in this connection is the fact that the shore line of the Pacific in general, coincides with the line of the western critical circle, deformed as a result of the twisting effect. No such correspondence is observed in the antipodal hemisphere, where the shore lines of the Atlantic and Indian Oceans are at a considerable distance from the eastern critical circle and from the submeridional mountain uplifts associated with it (the Atlantic and Indian submarine ranges).

In connection with the differences between the Pacific and the Indo-Atlantic shores, we should not forget the active creative work done by rivers, which deposit in the coastal areas a colossal amount of fragmental, sandy and /86
muddy material in the form of alluvial fans. These deposits, as they accumulate and are reinforced by vegetation, steadily increase the extent of the dry land. In this way the activity of rivers still further complicates the outlines of the continents. According to data of D. Gilluli (1955), the rate of coastal sedimentation for the whole earth amounts on the average to 36 cubic kilometers per million years per kilometer of shore line. However, high border ranges--the American and the Australian cordillera systems--prevent river discharge into the Pacific Ocean, directing it instead into the Atlantic and Indian Oceans, this still further complicates the contrast between the Pacific and the Indo-Atlantic types of shore line.

CHAPTER 4

LAWS OF THE FORMATION AND DISTRIBUTION OF MOUNTAIN BELTS

> The very greatest mountain chains are no more than subordinate members of those enormous structural phenomena which embrace the whole globe. One can investigate and describe the position of the layers and the structure of each range individually, but it is impossible to arrive at a correct expl nation of these phenomena without invoking the distribution of mountain chains in general.
>
> --E. Suess

The processes which deform the earth's crust are not uniformly intense, /87
either in space or in time. The revolutionary-critical epochs in the earth's history were times of great activity. In the last of these--the Alpine--there occurred the formation of the present-day Cordilleras and the Mediterranean Alpine-Caucasus-Himalayan mountain belt. The most significant mountains, mountain ranges, mountain systems and mountainous regions are not distributed at random, however; they are grouped in several zonal, submeridional and meridional mountain belts which embrace the whole planet. But the outlines of these formations would appear to be of random character, and the widths are extremely variable.

The Origin of Geosynclines and Mountain Belts

Since mountain belts exist all over the earth, it is clear that geosynclinal-orogenic deformation of the lithosphere must be regarded not as isolated phenomena, but rather in connection with deformation of the entire planet, and in connection with changes in the volume and figure of the planet as a whole. /88

In preserving its volume, the earth accumulates an enormous amount of heat within its interior (through transfer of a portion of potential gravitational energy into internal kinetic energy). The planet "heats up", and, on the heels of compression, there follows a temporary expansion of the earth. Preceding (and indeed causing) the epoch of expansion (during which the forces of repulsion predominate over the forces of attraction), gravitational compression is thereby itself temporarily negated. The initial geosynclinal stage in the development of a folded mountain belt is explained by processes associated with stretching of the earth's crust during an epoch of temporary expansion of the earth. In zones where tangential directions arising during general stretching of the lithosphere achieve the greatest magnitude, the lithosphere is thinnest; it is here also that we find the mobile belts of stretching--the geosynclines. Fractures, inevitably arising in zones of crustal stretching, open routes for the abundant rise of solutions of minerals, gas, oil and water. The increased "temperature" of the earth during this epoch favors the melting of large masses of abyssal material, particularly basalts, which are rocks with the lowest melting points; and this, in combination with increased permeability of the lithosphere, leads to a wide distribution of volcanic phenomena.

Thanks to the fact that the mobile belts of the lithosphere during the geosynclinal stage receive an abundant quantity of volatile substances, hot vapors and solutions from the depths below the Mohorovicic discontinuity, they differ from other portions of the earth's surface both dynamically and geochemically.

As heat obtained from the preceding contraction of the earth is exhausted, the expansion of the planet is again replaced by compression. Tectonic development during an epoch of compression is characterized by a deepening of geocynclinal troughs and by folding of the sedimentary strata which have filled these troughs. Folding, although expressed most clearly in geosynclinal zones (which are more plastic and flexible than platforms), is by no means restricted to geosynclines, taking the planet as a whole. This is indicated by the universal folding of the foundation of platforms, /89 which also serves as a reflection of the process of contraction, as a form of reaction of the lithosphere to the contraction of the earth's volume. Therefore, during an epoch of compression (which is the epoch of greatest contraction of the planetary radius), folding deformations necessarily develop with maximal intensity.

All that has been said above is supported by the fact that, apart from processes of compression and stretching of the earth's crust accompanied by pulsation of the terrestrial volume and figure, no other mechanism can support an explanation of the whimsical orientation of syneclizes and anteclizes (smooth troughs and rises which dismember platforms), since this orientation requires *the presence of alternately compressive and stretching* forces acting in all horizontal directions.

The mountains and adjacent depressions formed in an epoch of compression achieve their greatest heights and depths where, during the preceding epoch, sedimentation was particularly intense and prolonged--namely, in the most flexible and plastic portions of the lithosphere, the geosynclinal depressions. The complexity of the outlines and structures of mountain belts, so striking to every attentive observer, was evidently conditioned by the structural peculiarities of zones of thinning, in which the geosynclines appear, not uncommonly limited, moreover, to abyssal tectonic fractures. Just as the structure and the thickness of the crust, as well as the degree of its disintegration, do not remain unchanged, neither does the structure of mountain belts, since their form in the plane inevitably becomes complicated in the course of time.

Consequently, the structure of folded mountain belts is in part primary, being inherited from the initial, geosynclinal stage, and in part secondary, being formed as a result of the length history of their development.

Where Are Mountains Formed? The Law of Zonal Distribution of Mountain Systems.

Spatially, orogenic movements are limited to several, predominantly zonal, submeridional and meridional critical circles. These large and small circles are morphologically expressed on the face of the earth in the form of structural belts along which the uplifted portions achieve much greater heights and the depressed portions much greater depths, than anywhere else. /90

TABLE 4. Zonal Hypsometry of the Northern Hemisphere (After A. A. Tillo, 1889; abbreviated)

Belts	Mean Altitude in meters	Mean Depth in meters
80°—70°	550	630
70°—60°	360	890
60°—50°	470	2130
50°—40°	770	3650
40°—30°	1350	4150
30°—20°	740	4150
20°—10°	520	4100
10°— 0°	690	4020

For the Northern Hemisphere this is visually illustrated by the accompanying Table, from which it is evident that the most significant heights and depths are concentrated in the zone between 30° N and 40° N.

This table shows clearly the marked dependence not only of the height of the mountain uplifts, but also of the submontane and intermontane troughs, upon the factor of geographical latitude.

Somewhat later than A. A. Tillo, the German geomorphologist Albrecht Penck, in trying to determine the upper limit of terrestrial elevations, called attention to the fact that the highest altitudes on earth are concentrated between 27° and 30° N in the Northern Hemisphere, or along the 32nd parallel in the Southern Hemisphere. *All* altitudes above 8,000 meters, wrote Penck, lie in the Northern Hemisphere, within the zone mentioned, and highest known altitude in the Southern Hemisphere--Aconcagua (about 7,000 meters)--is also on the 32nd parallel (Table 5).

That mountain altitudes are generally less in the Southern Hemisphere than in the Northern is evident from Table 5.

TABLE 5. Zonal Distribution of Highest Altitudes

Northern Hemisphere			Southern Hemisphere		
Zone	Highest Altitude in Zone, in meters		Zone	Highest Altitude in Zone, in meters	
80-70° N	Petermann Peak	2,939	80-70° S	Peak in Queen Maud Range	5,180
70-60°	Mount Logan	6,050	70-60°	Mt. Stevenson	2,981
60-50°	Browne Tower	4,880	60-50°	Mt. Darwin	2,469
50-40°	Khan-Tengri	6,995	50-40°	Mt. Cook	3,764
40-30°	K 2	8,611	40-30°	Aconcagua	6,960
30-20°	Everest	8,847	30-20°	Ojos del Salado	6,885
20-10°	Citlaltepac	5,700	20-10°	Sajama	6,780
10- 0°	Cayambe	5,840	10- 0°	Chimborazo	6,272

An imaginary surface resting on the highest peaks of the world would be found to gradually rise moving from the poles toward the equator until approx- /91
imately the 32nd paralle, when it would drop. But here it is important to note that near the equator the surface would be higher than in the polar regions, and also it would, in general, be higher in the Northern Hemisphere than in the Southern.

The relationship between the height of mountain peaks and latitude can be traced out even within the Soviet Union, where an increase of heights toward the 35th parallel is readily apparent.

Thus, it is near the critical latitudes of ±35° that zonal mountains /92
achieve their greatest heights, and the associated depressions achieve their greatest depths. There can be no question that this fact is associated with the general structural plan of the earth.

The Origin of Mountain Parallels

Whereas the causes of variation in polar compression are effective over so long a period that the rise of abyssal movements within the earth is able to bring about a change in its form to correspond with new conditions, an increase or decrease in α produces a subsidence or uplift of the lithosphere of the equatorial zone which is tied in with a subsidence or uplift of the lithosphere of higher altitudes. The boundaries of these varied vertical movements runs along the critical 35th meridians.

TABLE 6. Highest Points in Soviet Mountainous Areas (After I. S. Shchukin, 1938; modified)

Mountainous Region	Highest Point	Latitude	Altitude in meters
Urals	Narodnaya	65°03'	1,894
Eastern Sayan	Munku-Sardyk	50°19'	3,491
Altay	Belukha	49°54'	4,506
Caucasus	El'brus	43°32'	5,633
T'ien-Shan	Khan-Tengri	42°29'	6,995
Zaalayskiy Range	Lenin Peak	39°20'	7,134
Academy of Sciences Range	Communism Peak	38°35'	7,495

As a result of the interaction of pulsational and pulsation-wave oscillatory movements, the amplitudes of pulsational oscillations in zones above ± 35° increase toward the poles, whereas in the equatorial belt they diminish within those particular belts. *The upland relief of Africa, Australia and South America is associated with the lesser tectonic mobility of the equatorial zone.*

With pulsational deformations of the earth and precessional oscillations of its rotational axis, there arise within the critical limits of ± 35° large gradients of vertical oscillatory movements and tangential stresses, which in their turn cause the appearance of abyssal fractures in the earth's crust together with associated underthrusts and overthrusts. Such is the possible chain of causes resulting in the pattern existing between folded and folded-block mountain structures, on the one hand, and the earth's critical zones, on the other.

Folded-block mountains are formed in those portions of a mountain belt, where, as a result of comparatively great rigidity and low plasticity of the earth's crust, a great role is played by fractures and by vertical displacement along individual blocks of the lithosphere. We find such mountains in the case of the Altay and Sayan systems of southern Siberia. If the possibilities for folding have been exhausted, or are completely absent, then /93
block mountains appear, or, if the elevation of the mountain system has been renewed, step-block mountains. The tectonic stresses of the belt of the 35th critical parallel did not appear everywhere at the same time, but rather in accordance with the stage of development of the figure and surface of the earth; also, they appeared unevenly, in connection with local features of the

structure and the preceding structural development of particular regions of the terrestrial surface. For instance, during the Paleozoic the Appalachian mountain system in America was formed as a part of the tectonic belt of the 35th parallel, while later on, during the Tertiary, the Alpine-Himalayan mountain system--the highest on the Eurasian continent and on the planet--was formed.

In addition, the belts of the 35th parallels, north and south, are interrupted by oceanic troughs: in the Northern Hemisphere by the Pacific and Atlantic Oceans, in the Southern Hemisphere by the Indian Ocean. Here, one is struck by a remarkable and quite characteristic fact--the absence of any very high or persistent mountain belts in these oceans. To this rule we find an exception in the case of the Azores in the Atlantic and the Hawaiian Islands in the Pacific: but these are associated not with east-west but rather with meridional or near-meridional mountainous uplifts.

This apparently strange characteristic of the ocean floor is entirely explainable. It is the result, first of all, of antithesis in structural development (the world ocean is subsiding while the continents are rising), which leads to a basic difference between the composition and structure of the ocean bed and that of the continents. Secondly, it is the result of the impossibility of any intensive sedimentation in portions of the world ocean which are far removed from land. Therefore, since there are no geosynclinal sediments (far removed from land) which are subject to compression, in the world ocean we find no folded mountains growing out of geosynclines, while the formation of latitudinal block mountains is prevented by the greater rigidity (in comparison with the granitic continents) of the existing basaltic ocean floor, which evidently presents too strong a resistance to the tectonic stresses of the 35th parallel. /94

It is of the greatest interest that on Mars, where there are no opportunities for geosynclinal development, and hence for the formation of folded mountains, tectonic stresses within the zone of influence of the 35th parallels have led to the formation of block uplifts, which, as a rule, are bounded by fractures (See Insert, Figure 24): in the Northern Hemisphere we find Elysium, Isidus Regio, Tempe, Arcadia and Olympus; and in the Southern Hemisphere, under the areographic latitude of 35°, a whole string of plateau-like elevations--Icaria, Phaethontis, Electris, Eridania, Ausonia, Hellas, Noachis, Argyre I, Protei Regio, Gigas and Thaumasia. The belts of fractures and block mountains near the 35th parallels are evidence of the unevenness of the planet's axial rotation. That the Martian mountains are block-type rather than folded is confirmed, in particular, by the prominent breaks in the planet's crust, observable to us in the form of branching belts of various width, referred to in the areographic literature by the unhappy term "canals". A clearly marked ring of fractures in the zone of 35° N (Figure 24) corresponds to the Pacific belt of fractures in our own Northern Hemisphere. On Mars, just as on the earth, we see the effect of twisting of the planetary surface around the axis of rotation.

A second critical parallel in both terrestrial hemispheres is 71°. As distinct from the zones of the 35° critical parallels, the surface of our planet near 71° N and S is much less disrupted by meridional structures and deformations. In the Northern Hemisphere, for instance, the Byrang Mountains in Taymyr, the northern ranges of Baffin Land, and the Brooks Range in North America are associated with the 71st parallel. In the Southern Hemisphere the 71st parallel marks the Cenozoic block structures of East Antarctica and also certain Cenozoic volcanic phenomena.

Fractures associated with the 71st parallels deviate in a direction close to the east-west; structures of meridional strike (for example, in the transition from the Urals and Pay-Khoy to their extension in Novaya Zemlya) determine the block structures, relief and outlines of the shores of both the Arctic and the Antarctic.

Asymmetry of the Northern and Southern Mountain Parallels /95

Turning our attention, now, from theory (Chapter 1, Figure 8-a) to observations, we find it evident that our theoretical prediction of the existence of antipodal critical parallels is completely justified.

The Northern Hemisphere block mountain systems belonging to the "belt of the great crustal fracture"--namely the Azores, the Atlas Mountains, the Pyrenees, the Alps, the Taurus-Dinarics, the Pamirs, the Kuen-Lun, the Himalayas, the mountains of Southern Japan and Hawaii, and the Appalachians--have as their antipodes only the Pampas Sierras of South America, the Cape and Drake Mountains in South Africa, and the Australian Alps in southeast Australia.

We find also an asymmetry between the northern and southern zones of the circumpolar critical parallels. This is exhibited in the precipitousness of the shores, in the sharp variation in altitudes on the coast of Antarctica, and in the presence of a deep-water trench within the zone of influence of the circumpolar parallel: the shore of the Arctic Ocean, by contrast, presents a more gentle transition between land and sea, while there is no circumpolar trench as in the Southern Hemisphere.

Thus, *as a consequence of their different rate of change in polar compression, not only are the two hemispheres disymmetrical* (the predominance of continental uplifts and dry land in the Northern Hemisphere, and of oceanic subsidences and water in the Southern), *but the antipodal mountain belts are different.* This is reflected in various mountain peaks (both very high, such as Everest and Aconcagua, and of medium height), and in the width and extent of the northern and southern mountain belts. *Given the same rate of variation in polar compression in the two hemispheres, so fundamental a diversity between the northern and southern halves of our planet could never have arisen.*

Mountain Meridians and Their Origin /96

In addition to the critical parallels of ± 35° and ± 71°, the western and eastern critical belts, and the various fractures, uplands and depressions associated with them there are two critical meridians on the earth, namely 60 - 120° and 150 - 30°. These meridians mark the position of a series of stretchings and compressions generated in the lithosphere by the epeirogenetic centers of the North and South Poles. With uplift of the polar zones there arise stretching tensions, and with subsidence of those zones, compression tensions. The cracks, fractures, slips and thrusts in the earth's crust which result from these stresses run from the poles toward the critical centers (the intersections of the 35th parallels with the western and eastern critical centers); they represent the most weakened sections of the lithosphere.

The meridian of 60° E marks the Urals and also the meridional block mountains which lie under the ice of East Antarctica. The other critical meridian, 150° E, marks the Verkhoyansk Range, the Cherskiy Range, and the Australian Cordilleras; its antipode, 30° W, marks the Mid-Atlantic Ridge, an enormous meridional submarine range in the Atlantic, whose length is approximately 10,000 kilometers, width about 550 kilometers, and height above the ocean floor 3.5 - 4 kilometers.

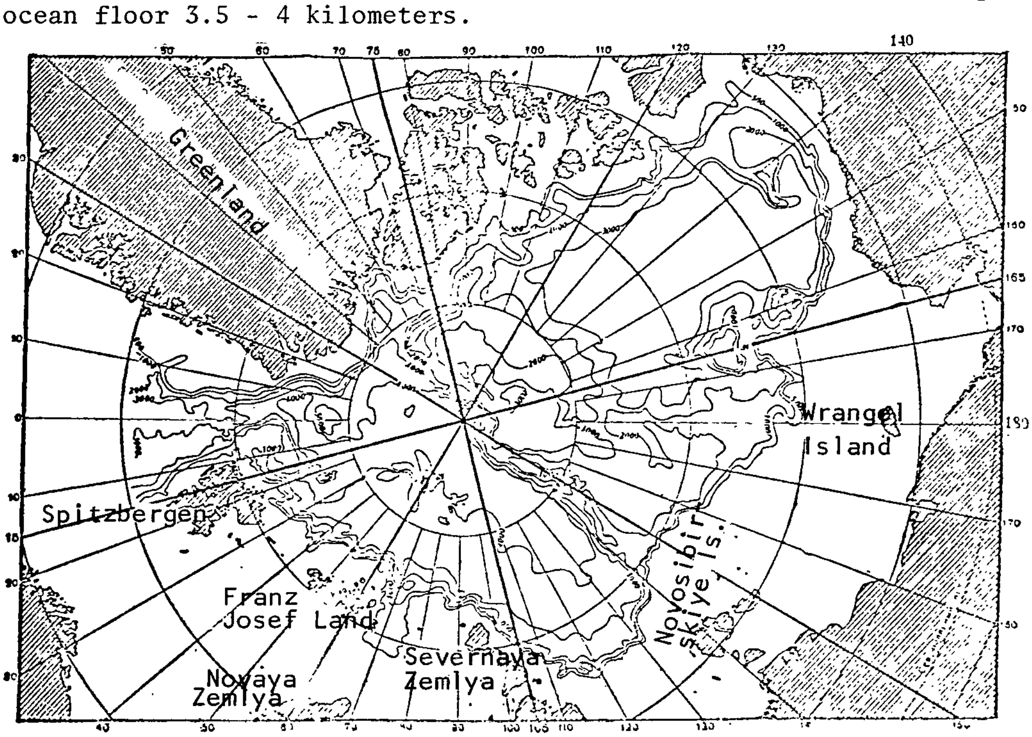


Fig. 28. Relief of the Arctic Ocean Floor. (After Ya. Ya. Gakkel', 1957; Active Meridians Superimposed). 15 - 165°, 105 - 75° Are The Extemum Meridians; 60 - 120°, 150 - 30° Are the Critical Meridians.

In the Arctic various meridional fractures follow the critical meridians; these fractures are responsible for the shape of the eastern coast of Greenland and for the intensive volcanism of Iceland. Novaya Zemlya and the submarine Lomonosov Range, discovered by Ya. Ya. Gakkel' on 27 April 1948 also lie on these meridians.

The discovery of the Lomonosov Range is very interesting. The first suggestion of the existence of an underwater Arctic range joining the Verkhoyansk Range in Northeast Asia with Ellesmere Land was advanced by the eminent Austrian geologist Eduard Suess. In studying the folded Triassic deposits of the Evrek Strait and the folded mountains stretching from Greely's Fiord to Scoresby Sound in the Canadian Arctic archipelago, and comparing them with data collected by the Russian investigator E. V. Toll' on the Triassic rocks of Verkhoyansk Kray, Suess concluded that "these folded mountains exhibit the signs of the Asiatic arcs, and can be assumed to represent the terminus of an Asiatic formation extending across the North Pole" (1909, pages 283 - 284). Subsequently it was established that the folded mountains of Grant Land and Ellesmere Land are of greater age (Schuchert, 1923; Cox, 1935) than the Verkhoyansk Range; and this led to Suess's hypothesis of a submarine range in the Arctic being laid aside and forgotten. But at the end of the forties of this century, V. A. Tokarev, N. Ye Mart'yanov and the present writer, although using absolutely different lines of approach, concluded that such a submarine range must exist. These three researchers reached the same conclusion independently, and the latter two of them had no knowledge of Suess's earlier surmise. /98

In the case of the Antarctic we find meridional block structures associated with the critical meridians; these extend all the way from the sea to the South Pole. In this region Cenozoic vulcanism is also associated with the critical meridians (Figure 29).

The conception of critical (or "mountain") meridians is of great prognostic value. Following the discovery of the Arctic submarine range this was confirmed once again by the work of the Third Soviet Continental Antarctic Expedition, the paricipants of which discovered a large group of hitherto unknown block mountains, lying within the zone of influence of the critical meridian of 60°. These mountains are only a part of the meridional sector of block structures (horsts and grabens) stretching from Prydz Bay to the South Pole itself, and possibly even farther toward Amundsen Sea[1]. This sector is at least 500 kilometers wide (P. S. Voronov, 1959).

A considerable part of the length of the so-called mountain meridians (60°, 150°, 120°, 30°) lies in the sea, and the 30th meridian (associated with the Mid-Atlantic Range) is entirely in the sea. The 60th meridian (and

---

[1] The meridional depression lying in this sector which was named "Valley of Moscow State University" was so designated in honor of the Third International Geophysical Year. It is 1,300 kilometers in length.

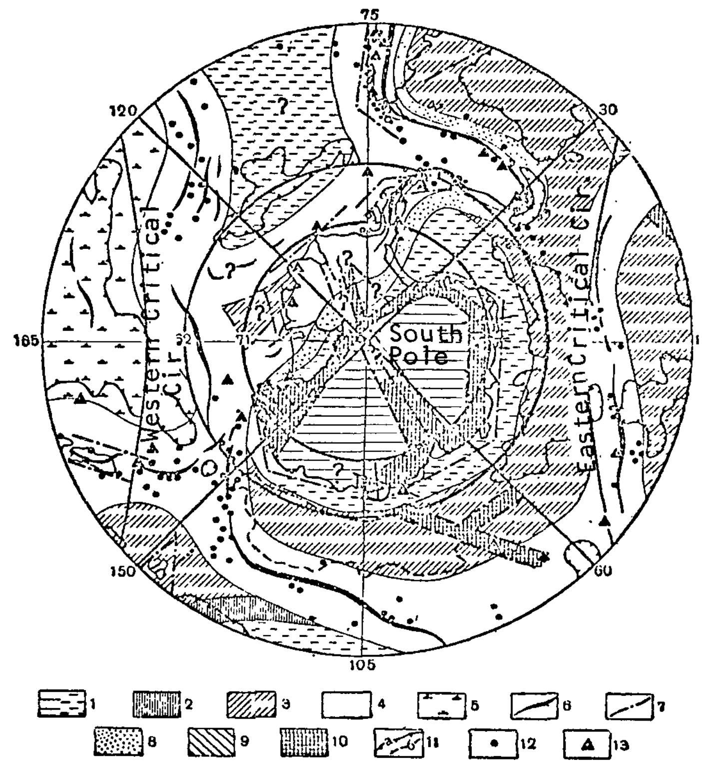


Fig. 29. Structure of Antarctica and the Ocean Floor; Critical Circles of Deformation. (The Structural Scheme is That of P. S. Voronov, 1960; the Critical Circles Are as Conceived by the Present Writer, 1955, 1958).

60 – 120°, 150 – 30° are the Critical Meridians; 71° is the Critical Parallel. On the Left is the Western Critical Circle, On the Right the Eastern.

1 - Post-Proterozoic Platforms; 2 - Regions of Caledonian Folding; 3 - Regions of Hercynian Folding; 4 - Regions of Alpine Folding; 5 - Simatic Region of the Pacific Ocean; 6 - Direction of Axes of the Main Folds; 7 - Direction of Main Cenozoic Fractures; 8 - Alpine Foredeeps; 9 - Region of Presumed Relics of Caledonides; 10 - Certain Cenozoic Block Structures; 11 - Oceanic Basins of Greater Depth: a) 5,000 m; b) 4,000 m; 12 - Epicenters of Modern Earthquakes; 13 - Cenozoic Volcanoes.

its antipode, the 120th) is in the sea south of the Tropic of Cancer (associated with the Indian and Pacific submarine? ranges). The central part of the 150th meridian is in the sea. The so-called mountain parallels (± 35°) are interrupted by oceanic troughs, but this is not true of the mountain meridians. We find that the Ural Mountains have a continuation in /100
a submarine range in the Indian Ocean; the North American Cordilleras,

similarly, continue in a range beneath the Pacific; and the Australian Cordilleras and the Verkhoyansk Range "take up" along the meridian in the Lomonosov Range.

Meridional mountain systems are of greater breadth and length than zonal mountain systems. The underwater mountain ranges of the Arctic (the Lomonosov), the Indian and the Atlantic Oceans, and possibly also the Pacific, are not folded structures, but rather block-type elevations: in other words, it was not folding, but rather the movement of blocks of the lithosphere along fractures which played the main role in their formation. As distinct from the mountain ranges of the continents, the oceanic ranges are composed mainly of basaltic rather than granitic material.

The origin of underwater oceanic ranges is regarded, at the present time, as being associated with planetary tectonic fractures and volcanic processes[1]. Judging by the terraced character of both the eastern and the western slopes of the Pacific Range (Kh. Khess, 1955), one may presume that the range was formed in stages; this would account for its external, step-like, block character. As a result of investigations conducted during the past few years it has become increasingly clear that not only the Mid-Atlantic Range, but also a number of other mountain structures, both above and below sea level, were formed basically by vertical rather than horizontal movements. In the oceanic portions of mountain belts, radial uplifts acting on the surface of the earth from within the planet exerted a still more substantial influence on the external character of ranges than they did on ordinary dry land.

Along with the rather important factor of mountain-formation, we must naturally consider the process of serpentinization. I refer to the fact that in folded mountains arising from geocynclines, and also in oceanic ranges, there is a wide distribution of ultrabasic green rock, particularly the serpentinites[2].

In the overwhelming majority of cases the intrusion of serpentinites /101
into the earth's crust coincides with the first great deformation of the crust (E. Suess, 1909). This circumstance enables us not only to arrive at an accurate estimate of the age of any given mountain system (on the basis of the age of the serpentinites), but also to support the hypothesis of Kh. Khess (1955) to the effect that mountain ranges (and particularly submarine ranges) may have arisen as a result of serpentinization.

But what is the essence of this process, what is its tectonic significance, and how can its marked localization in mountainous belts be explained?

[1] Dzh. T. Vil'son, "Geophysics and the Growth of the Continents", *Priroda*, No. 8, 1959.
[2] According to Kh. Khess (1955) this has been firmly established for the Mid-Atlantic Range.

In the chapter on geographical homologies we discussed the abyssal process of the formation of quartz, which is the principal component part of the granitic lithosphere of the continents. This process takes place at temperatures of 1,000 - 1,500°C, and is accelerated by any lowering of external pressure. Quartz, which has a lower density than the forsterite which is formed along with, "floats" along cracks (if any are present) and rises from the mantle into the lithosphere. The conditions which predominate during an epoch of earth expansion (increased temperature, lowered pressure of upper layers on those underneath, the presence of abyssal cracks) favor the abyssal process of quartz-formation and the build-up of the granitic lithosphere from underneath.

When an epoch of compression sets in, there is a reduction of the earth's "temperature", the pressure exerted by overlying strata increases, and the cracks in the lithosphere are closed, remaining open only in those areas of the earth where the gradients of vertical oscillations are greatest (that is, areas coming under the influence of the critical circles). The reaction of quartz-formation is either attenuated, or, if conditions of compression are extremely unfavorable for it (as when the temperature drops below 1,000°C), halted entirely.

When the temperature drops to 500°C the process of serpentinization begins in the mantle. The forsterite formed during the epoch of expansion and "abandoned" by the rising quartz, enters into a reaction with water (which is given off in a free state during earth compression) and is converted into serpentine:

$$2Mg_2SiO_4 + Mg_2SiO_6 + 4H_2O = \qquad (13)$$

forsterite + enstatite[1] + water

$$= 2(3MgO \cdot 2SiO_2 \cdot 2H_2O) + Q \text{ kcal}$$

= serpentine + heat

/102

During serpentinization the volume of the rock increases by some 25 percent--which is to say by an amount 6 times as great as during the formation of quartz (4 percent). This inevitably results in a rise of the lithosphere by 3 - 5 meters if there is an influx of water. Kh. Khess (1955) believes that this is precisely the way in which the Mid-Atlantic Range rose 3.5 - 4 kilometers above the ocean floor.

Serpentinization occurs mainly during phases of compression, when the majority of fractures in the lithosphere have been closed, and only abyssal

[1] Enstatite is a mineral which, along with fosterite, clinoenstatite and other minerals, forms the rocks of the peridotite group composing the earth's mantle.

fractures associated with the critical circles of the ellipsoid remain--to serve as routes for the movement of water. It becomes understandable, therefore, why the process of mountain-formation, and the radial uplifts associated with it, is controlled by the critical circles, and particularly the critical meridians.

CONCLUSION

> ...It has been sufficiently demonstrated that different forces may produce the same results, and that the condition of the terrestrial globe, its orbital movement around the sun, its axial rotation, and even the movement of the moon around the earth, may very well be strictly interconnected, established opinion to the contrary notwithstanding.
>
> --Ye. V. Bykhanov

We now see that the terrestrial globe, being compressed by the force /103 of gravity and compacted in its depths through physico-chemical transformations and denser "packing" of particles, is also subject to asymmetrical deformation by rotational froces, which give it the figure of a *cardioidal ellipsoid.* The compression of the earth is accompanied by a liberation of potential gravitational energy--the basic source of "power" for tectonic processes. Since acceleration of the earth's rotation is not constant (because the compaction of terrestrial material and the contraction of the earth's volume are not constant), the secular deceleration of the earth's rotation which results from tidal friction is not constant either: just like an animal's heart, the earth is continually pulsating, and changing its volume and shape. Every epoch of compression is succeeded by an epoch of expansion. This leads to the formation of cavities within the body of the planet, and to the formation of lines of maximal radial stress on the surface--the so-called *extremum circles.* Between these are the *critical circles,* which mark the boundaries of radial movements of various direction. These interrelated deforming forces, derived from the earth's compression and rotation, result in tectonic movements in the mantle, the lithosphere and the hydrosphere. They create the zonal, meridional, submeridional and segmental structures of /104 the earth's crust, as well as the alternating transgressions and regressions of oceanic waters. Moreover, shifts in terrestrial masses of water alternate in space as well as in time, thus bringing about transgressive and regressive epochs (the spatial alternations are associated with fluctuations in the figure of the earth, the time alternations with fluctuations in its volume).

The enormous energy liberated during abyssal compression of the earth is distributed unevenly over the planet's surface. It is localized in the zones which come under the influence of the active circles and centers of the terrestrial ellipsoid: the energy is directly proportional to one's nearness to the circles and centers. In the belts of the critical circles we find mainly a concentration of the energy of compression; in the belts of the extremum circles, mainly a concentration of kinetic energy.

The difference in the potential energies in opposite hemispheres, which is associated with the earth's asymmetry with respect to the equatorial plane and the plane of the 105 - 75° meridian, in its turn produces a difference in the activity of the antipodal geodynamic circles.

The distribution of the largest objects of terrestrial relief (the continents and oceans) is subject to the law of the extremum active centers and circles, while the distribution of mountain zones is subject to the law of critical active circles. The extremum active centers and circles are epeirogenetic; the critical active circles are orogenetic.

The epeirogenetic active circles and centers in their turn are divided into two groups--the *proper epeirogenetic* group associated with the formation of continents, and the *thalassogenetic* group, associated with the oceans. Oceanic subsidences and continental uplifts are balanced against each other, mutually related, and antipodal in distribution and development. It is along the critical lines that we observe the greatest uplifts and subsidences on the earth's surface; these are not sharply marked off from each other in the spatial sense, as are the continents and oceans, but instead co-exist within the same mountain belts. The rise of "kernels of growth" of the continents took place in regions under the influence of the epeirogenetic centers; the rise of fold-block and block mountains (the former within the limits of continents, the latter within the limits of oceans) took place within zones /105 under the influence of the orogenetic circles of the terrestrial ellipsoid.

The continents and oceans of our planet are distributed as follows, on the basis of four epeiro- and thalassogenetic centers, and three epeiro- and thalassogenetic circles:

$(\varphi = 0°,\ \lambda = -165°)$: the "pole" of the Western Hemisphere--the *Pacific thalassogenetic center;*

$(\varphi = 0°,\ \lambda = 15°)$ - : the "pole" of the Eastern Hemisphere--the *African epeirogenetic center;*

$\varphi = 90°$ - : the pole of the Northern Hemisphere--the *Arctic thalassogenetic center;*

$\varphi = -90°$ -: the pole of the Southern Hemisphere--the *Antarctic epeirogenetic center;*

$\lambda = 105—75°$ - , the great circle of the epeirogenetic meridian of the minor equatorial axis;

$\varphi = 62° —$: the small circle of the epeirogenetic parallel; and
$\varphi = —62°$: the small circle of the thalassogenetic parallel.

As a result of the interrelationship and interaction of the epeirogenetic meridian and parallel in the Northern Hemisphere, two additional epeirogenetic centers exit:

$(\varphi = 62°, \lambda = 105°)$, the Siberian

and

$(\varphi = 62°, \lambda = -75°)$, the Canadian.

The epeirogenetic centers of South America and Australia are associated with the circle of the epeirogenetic meridian of 105 - 75°; they are within the zone between the 35th (critical) parallel and the equator.

Mountain systems are distributed on the basis of eight large and small critical circles. There are four small antipodal circles formed by the critical latitudes of ± 35° and ± 71°, two small antipodal critical circles (western and eastern), and, finally, two great circles, the critical meridians 60 - 120° and 150 - 30°, which of course intersect at the North and South Poles.

The formation, development and distribution of the oceans, continents and mountain belts are related (1) with the formation of the moon in the immediate vicinity of the earth, and with the subsequent removal of the planet /106 as a result of tidal interaction in the Earth-Luna system, and (2) with tidal braking and oscillatory variations in the earth's rotational velocity. Shifts in the poles of rotation have served as a substantial factor in rejuvenating the ancient planetary relief.

The tectonics and relief of the earth's antipodal critical circles are asymmetrical as regards their development. This structural difference was brought about by the asymmetry of the earth with respect to the equatorial plane and the epeirogenetic meridian of 105 - 75°.

The Northern Hemisphere is basically continental in character, the Southern Hemisphere basically oceanic. The shores of the northern continents are very uneven and varied in outline, whereas those of the southern continents are smooth. In the north we find a "great fracture in the earth's crust", and an alpine system of folded mountains in the Southern Hemisphere there is nothing equivalent to these formations[1].

No less significant are the differences between the Eastern Hemisphere (pole at $\phi_e = 0°$, $\lambda_e = 15°$), which is continental in character, and the Western Hemisphere (pole at $\phi_w = 0°$, $\lambda_w = -165°$), which is oceanic in

[1] The difference in the structure and development of the northern and southern sectors of the lithosphere has attracted the attention of many writers: A. P. Karpinskiy (1888), D. G. Panov (1949), N. I. Leonov (1949), V.V. Belousov (1954) and A. B. Ronov and V. Ye. Khain (1954 - 1957), etc.

character. The Pacific Ocean is rimmed by a gigantic ring of mountains, volcanoes, superabyssal fractures and earthquake zones; Africa is an antipodal ring of lesser fractures and earthquake zones, to which the Caucasus, the Alps, the Atlantic, the African-Antarctic and the Indian mountain ranges are subsidiary.

The meridian of 105 - 75° is no mere conventional line of demarcation like the Greenwich meridian; it represents the physical boundary between two distinct hemispheres, in which the earth's crust presents quite different characters. In the Upper Paleozoic and the Triassic strata of the Pacific area we find subsidences (East Asia, western part of North America), whereas in the "African sector" uplifts have taken place (Europe, eastern part of North America). During the Jurassic and Cretaceous periods, on the contrary, there were significant uplifts in the Western Hemisphere which corresponded to maximal subsidences in the east (V. V. Belousov, 1954-a, 1955). /107

The asymmetry of geological space and the antipodal character of our oceanic and continental areas, the Pacific Ocean and Africa, the "Southern Ocean" and the northern belt of continents, can be regarded as the consequence of unevenness in the radial movements in antipodal hemispheres--east and west, north and south. *Africa*, a positive form of megarelief, arose as a result of a *lag* in the process of general secular subsidence of the Pacific and the African segments of the terrestrial ellipsoid. The *"Southern Ocean"*, a negative form of megarelief, was formed as a result of a *lag* in the process of general secular *uplift* of the northern and southern zones of the ± 62nd epeirogenetic parallels. Phenomena like the rise of anticlinal uplifts in a subsiding surface as the result of a lag behind the general level of subsidence, or the appearance of large saddles as a result of lag behind the general uplift of a mountain range (Yu. K. Yefremov, 1954), are well-known in the morphology of small forms of relief.

In connection with the influence of the Circum-Pacific and Circum-African critical circles, in the Northern Hemisphere east of the meridian 105 - 75°, we find a predominance of northeast strike in fractures, the direction of rivers, folded ranges, and shore lines, but a predominance of northwest strike to the west of that meridian.

To this correct picture of the earth we must add something more--the all-planetary effect of twisting, which very tangibly emphasizes the northwest orientation of large elements of the terrestrial surface; as is well-known, this effect is highly characteristic of our planet.

* *
*

When the rocks which compose the surface of our planet were first deposited they were more basic in chemical properties than they are today. Moreover, it is believed that the sialic layer was entirely lacking. Subsequent development led to the appearance of individual generalized granite

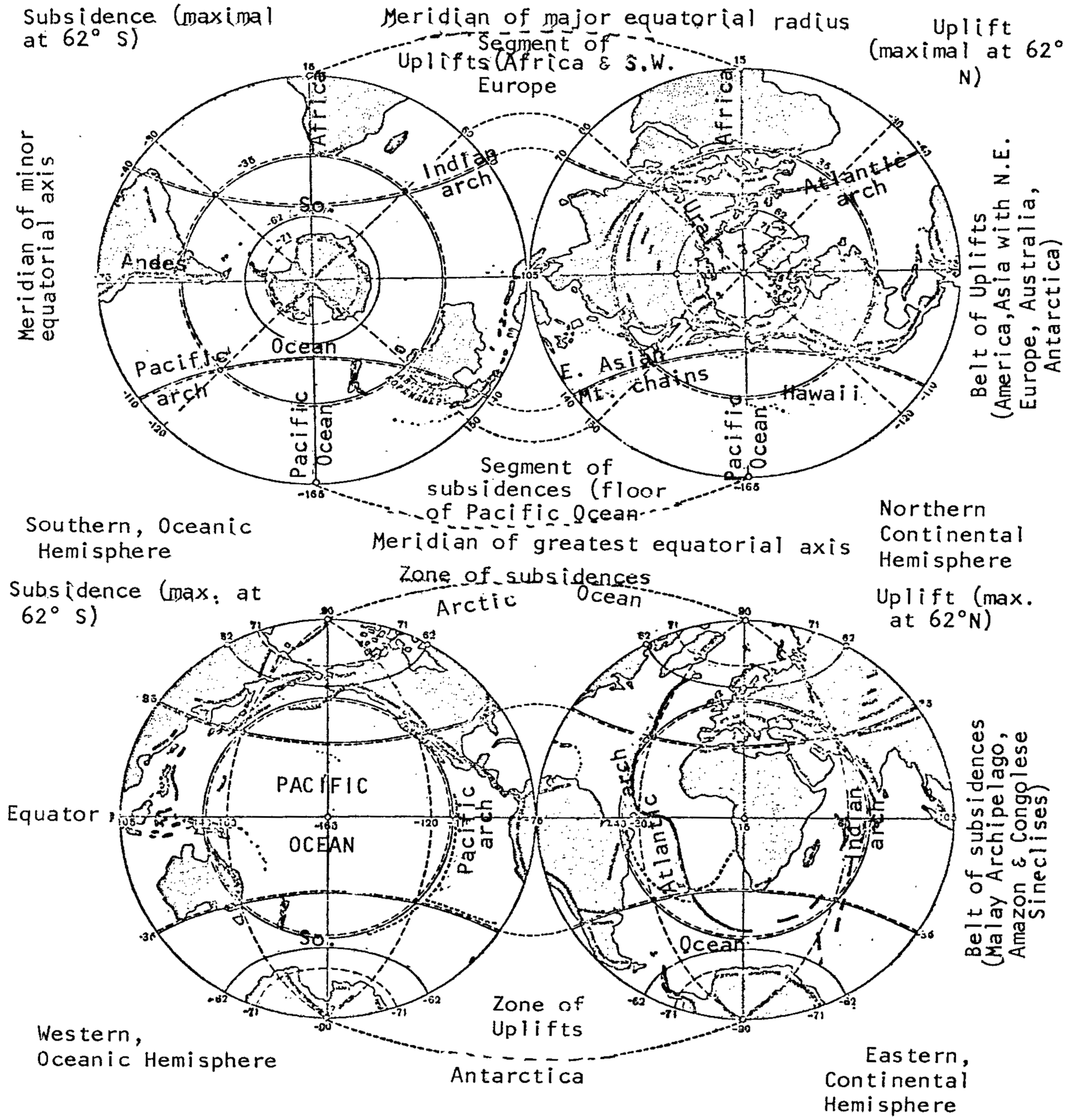


Fig. 30. Symmetry and Antisymmetry of the Plan of the Earth. λ_e = 15 - 165° is the Circle of East-West Symmetry of Relief and Structure of the Earth; λ_0 = 105 - 75° is the Circle of East-West Antisymmetry of Relief and Structure of the Earth; ϕ_0 = 0° is the Circle of North-South Antisymmetry of Relief and Structure of the Earth; and ϕ_0 = ±71.6 is the Circle of Antisymmetry of the Polar Regions.

spots within the regions influenced by the epeirogenetic centers. These spots
gradually increased in diameter, increasing in the downward direction through
the influx of sialic material from the mantle. Steady growth in the size of /110
the continents in directions away from the epeirogenic centers may have been
associated with the exothermic character of the process of SiO_2-formation.

Once begun, this process was self-sustaining, since the heat given off favored its development "in breadth" and further "melting" of the granite spots in the horizontal direction.

In examining the development scheme of North America illustrated in /111
Figure 31, one can discern at first glance a very characteristic trait of the
growth of this continent. Each more youthful zonal addition to the primary
ancient archicontent surrounds the more ancient additions, moving round them /113
on the side of the sea and profoundly changing their outlines. In this
process, the concentric growth of the continent proceeds asymmetrically,
unevenly, accelerating and developing now on one side, now on another.

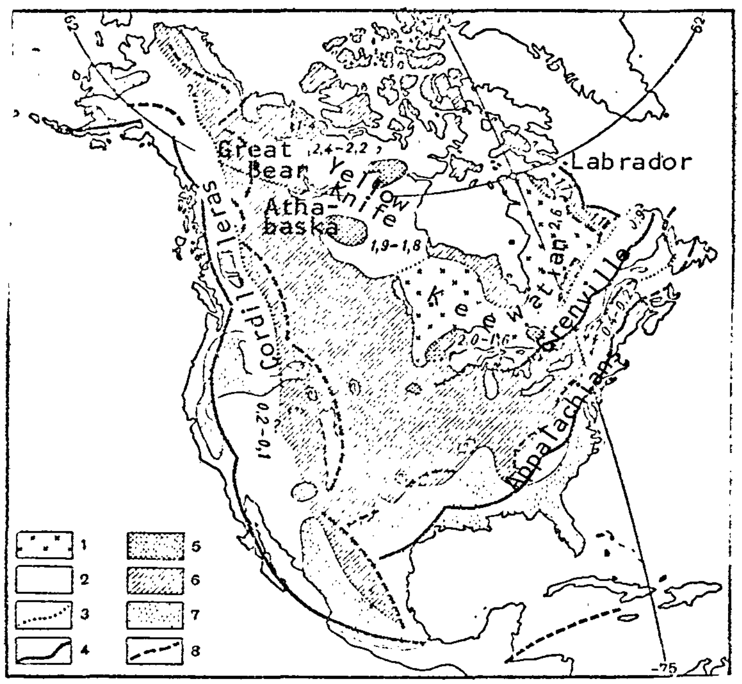


Fig. 31. The Developmental Scheme of North America. (After Dzh. Vil'son,1949. Active Circles and Centers Superimposed). Legend: Primary Provinces: 1 - Green Rock Nucleus; 2 - Other Provinces; 3 - Province Boundaries; 4 - Primary Arches. Secondary Covers: 5 - Proterozoic; 6 - Paleozoic; 7 - Meso-Cenozoic; 8 - Secondary Arches. The Figures Denote Ages in Billions of Years.

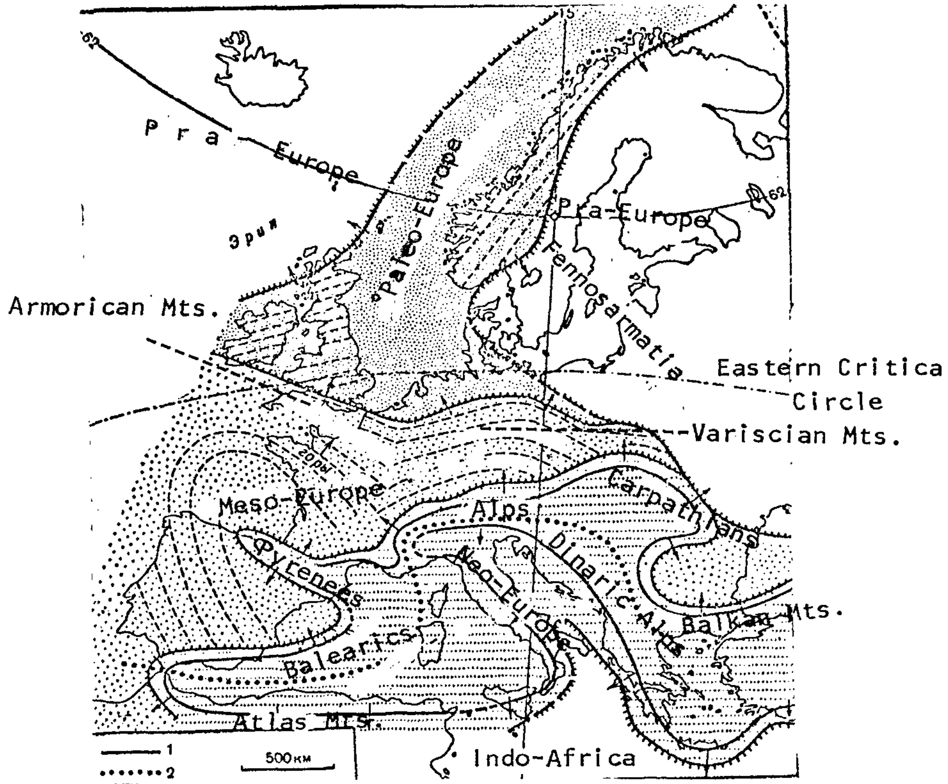


Fig. 32. Developmental Scheme of Europe. (After G. Shmille, from S. Bubnov, 1934) and Its Tectonic Breakdown.
Pra-Europe--Ancient Archean Center of Stabilization;
Paleo-Europe--Europe's Acquisitions Furing the Caledonian Cycle;
Meso-Europe--Europe's Acquisitions During the Variscian Cycle;
Neo-Europe--Europe's Acquisitions During the Alpine Cycle.
1 - Main Line of Alps, 2 - Boundary of Northern and Southern Folding.
The Eastern Critical Circle Divides Europe into Two Sharply Different (As Regards Structure and Age) Parts: the Northeastern and the Southwestern. The Former is Subordinate to the Baltic Shield and the Urals, The Latter to the Caucasus, the Alps and the Mediterranean Sea.

Analogous patterns can be traced out also for the Siberian Platform--a very ancient massif of the Asiatic continent[1] located in the region of influence of the epeirogenetic center 105° E, 62° N. The beginning of the geological history of Siberia is lost in the remote times of the earth's youth.

1 Henceforth, we shall treat Europe and Asia separately, since they have independent genetic centers.

As in the case of North America, there were gradual concentric accretions of younger and younger material added to the shores of the ancient Siberian nucleus of Asia. During the Paleozoic, for example, the Siberian Platform was framed on the northwest by the folded chains of the Sian Mountains; and during the Mesozoic it acquired the present northeastern part of Siberia. The characteristic feature of the younger structures of the Siberian Platform is their arc-type dispostion--attachment to the rim of the more ancient and more rigid nucleus around which they were formed.

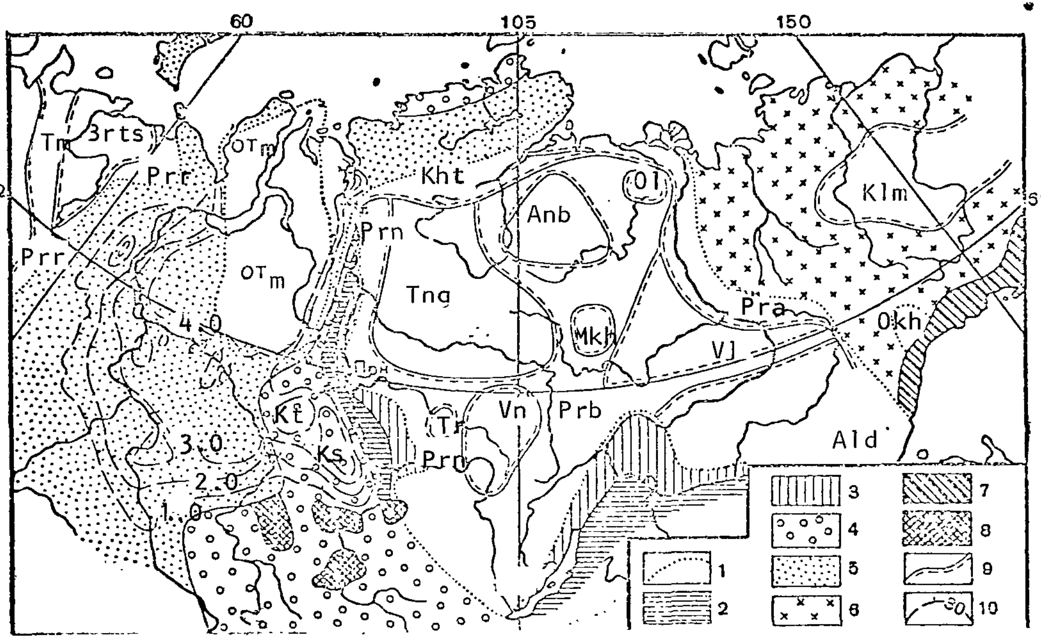


Fig. 33. Developmental Scheme of Siberia and Its Tectonic Breakdown (After V. I. Dragunov, 1960, with Modifications and Addition of Active Circles). 1 - Regions of Pre-Riphean STabilization and Their Outlines; Regions of Post-Riphean Stabilization; 2 - Eugeosynclinal Zones of Baikal Continent; 3 - Miogeosynclinal Zones of the "Baikal" Continent; 4 - Caledonian Folded Region; 5 - Hercynian Folded Region, 6 - Mesozoic Folded Region; 7 - Cenozoic Folded Region, 8 - Intermountain Areas; 9 - Outlines of Foredeeps, Syneclizes, Anteclizes, and Certain Median Masses; 10 - Contour Lines of the Surface of the Foundation of the West Siberian Lowland.

The Siberian Platform. Foredeeps; Prî - Prîyenîseyskîy, Prb - Pribaykal' skiy, Prv - Priverkhoyanskiy; Kht - Khatangskiy. Syneclises: Tng - Tungusskaya (Kureyskaya); Vl - Vilyuyskaya. Anteclises: Tr - Turamskaya; Anb - Anabarskaya, Ald - Aldanskaya; Ol - Olenekskoye Uplift.

The Russian Platform. Tm - Timan; Brts - Barentsev Massif; Prr - Pirural' skiy Foredeep; Otm - Obsko-Tazovskiy Massif. Continued next page......

Massifs: Okh - Okhotskiy; Klm - Kolymskiy.

Depressions: Ks - Kassikaya; KT - Ketskaya.

The Siberian Platform, along with the Anabar Massif, which is its primary center, is the most ancient dry land of the Asiatic continent; it is around this nucleus that the present continent of Asia has been formed in succeeding stages of geological history. /114

Figure 34 illustrates the build-up of Australia in a semicircle from its western portion toward the east--toward the young mountain arcs stretching from New Guinea to New Zealand. The asymmetry in the growth of the continent is expressed most strongly in the features of relief.

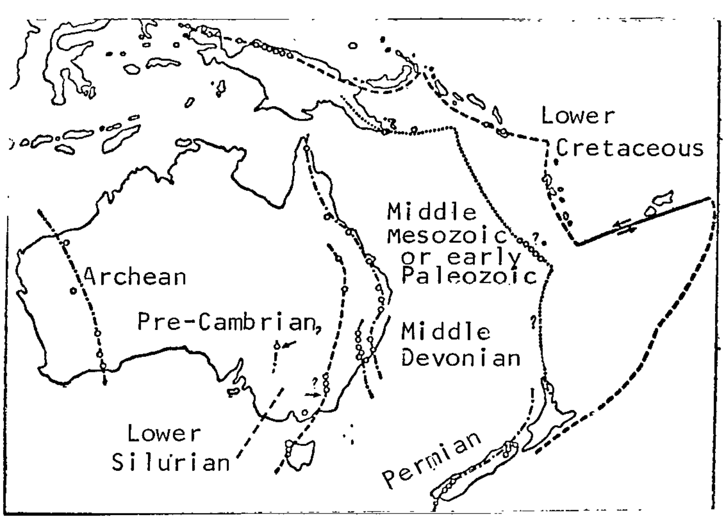


Fig. 34. Developmental Scheme of the Serpentinite Belts of Australia (After Kh. Khess, 1955).

The global scheme of the development of the continents in connection with active centers and circles of deformation of the terrestrial ellipsoid is shown in Figure 35, which shows the ancient stabilization nuclei of the platforms within the system of active meridians and parallels.

Directed variations in the development of the lithosphere are expressed in a steady increase in the sialic granite shell away from the epeirogenetic active centers. The continents have increased not only through the advance of sialic material from below, /115 which thus increases the thickness of their lithosphere, but mainly through growth in the horizontal direction from accretions added to their boundaries. The mean rate of thickening of the continental lithosphere is 10 - 40 meters per million years; but the horizontal increase amounts to 0.75 - 20 kilometers for the same period (V. I. Popov, 1955).

Of the present-day oceans, the Pacific is segmental; the Atlantic and Indian are meridional; and the Arctic and Circum-Antarctic are zonal. The

Pacific, the Circum-Antarctic and the Arctic are the most ancient of these waters; the Atlantic and Indian are younger, being secondary formations subsidiary to the Pacific.

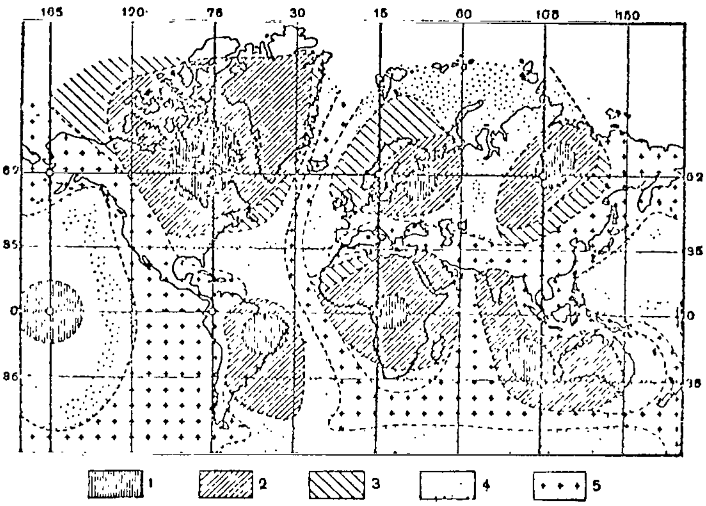


Fig. 35. Global Scheme of Development of Platforms (After V. V. Belousov, 1948, with Modifications, Active Meridians, Parallels and Centers Superimposed):
1 - Ancient Stabilization Centers;
2 - Caldeonian Platforms; 3 - Growth of Platforms by the Hercynian Cycle; 4 - Growth of Platforms by the Alpine Cycle;
5 - Alpine Geosynclines.

As regards position on the globe and origin, the modern continents can be divided into four groups: northern, including North America, Asia and Europe; equatorial, including only Africa; southern, including South America and Australia; and polar, including only Antarctica. /116

Although the primary "growth nuclei" of all the continents are essentially very ancient--Early Archean, or possibly even Pre-Archean[1], so that their age amounts to more than 3 billion years--the age of the continents themselves, just like that of the oceanic troughs, is quite variable.

Africa is evidently the most ancient of the continents. It is there that we find the earth's oldest rocks, whose age, based on preliminary estimates, is not less than 4 billion years (See Appendix III). In the case of the northern continents, the greatest age has been determined for biotite discovered in 1958 within magmatites on the Kola Peninsula.

Throughout the course of geological history the ancient continental nuclei have functioned as active centers of the most intensive intrusive activity. They have been sites for the withdrawal of material from subcrustal and deeper layers of the mantle--in contradistinction to the thalassogenic and oceanic regions, which have served as enormous reservoirs for secular

[1] P. S. Voronov and A. Ya. Krylov (1961) give a figure of 1.84 billion years for the age of the most ancient of known rocks in Antarctica. But this does not exclude the possibility of the discovery of crystalline rocks of still greater age in the Antarctic.

accumulation and subsidence of the mantle.

With the epeirogenetic centers of the Northern Hemisphere are genetically associated the systems of radial and concentric fractures which determine the outlines of certain river and lake systems. The directions of some sections of the shore lines in the northern parts of Asia and America (Figure 36) are also associated with those systems. The concentric fractures are also responsible for the geochemical belts of mineralization which surround the ancient stabilization nuclei of the northern continents.

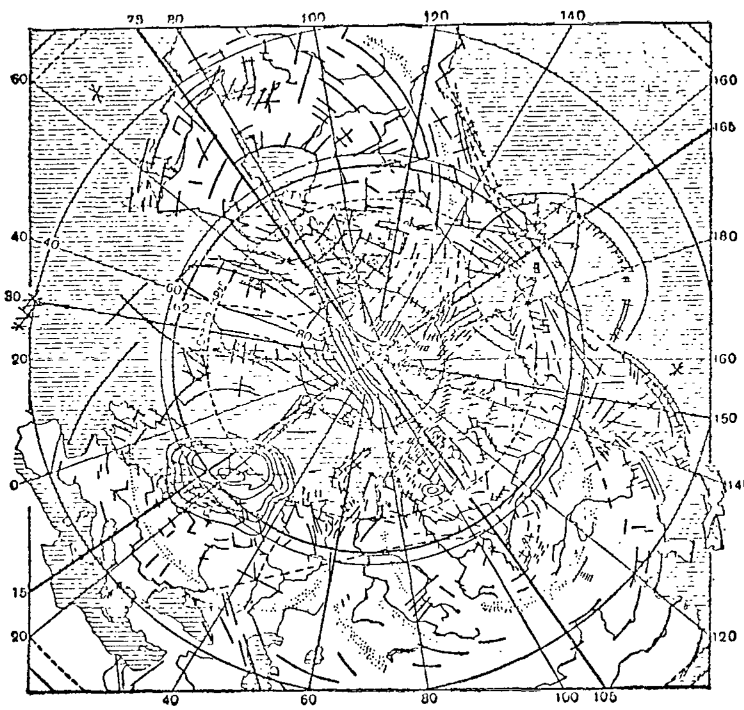


Fig. 36. Epeirogenetic Centers of the Northern Hemisphere and Tectonic and Geochemical Phenomena Associated With Them (Compiled by Ya. Ya. Gakkel'). The Sketch Shows the Basic Lines of Fractures, the Lines of Even Uplifts of the Baltic Shield, and the Geochemical Belts of A. Ye. Fersman and A. P. Karpinskiy (Shown in Shading). (The Sketch is Drawn Without Allowance for Distortion Introduced by the Cartographic Projection).

Being very ancient, the primary continental nuclei, from the time of the Proterozoic, have always been comparatively elevated lands not subject to intrusions of the sea. Ya. Ya. Gakkel' (1957), in tracing through and analyzing the developmental patterns of the northern epeirogenetic centers and the geological, geochemical and geomagnetic phenomena associated with them, concludes that during the Archean and Mesozoic these centers occupied the same symmetrical position with respect to the North Geographic Pole which they do at the present time. It follows from this that "there have never been any very perceptible shifts of the earth's axis of rotation ...since the time of the Archean" (p. 125). N. S. Shatskiy, somewhat earlier, expressed a similar point of view (1955). /117

V. I. Dragunov, in 1957 - 1960, studied the tectonic dislocations of the Asiatic portions of the USSR in the zone of the epeirogenetic parallel of 62° N, and was able to demonstrate that here, beginning with Pre-Riphean time, there were quite significant transformations of the geological structures (See Figure 33). /118 This circumstance, together with certain additional features observed in the structural plan of the European portion of the USSR, Scandanavia and North America in the zone of 62° N, served as confirmation of the ideas of Shatskiy and Gakkel'. The results of these paleoclimatic reconstructions, used as demonstrations of the shifting of the geographic poles, may be associated with the inclination of the earth's axis to the ecliptic, and also, in some degree, with a zonal shifting of the continents and of their individual parts, subject to the law of the general zonality of the structure of the earth's crust (V. I. Dragunov, 1960). Here we must assume that between the positions of the geographic and the magnetic poles there was simply no connection at all (P. S. Voronov, 1960 a), or that such a connection was very complex and not immediately evident.

P. S. Voronov (1960 a), having established the Meso-Cenozoic age of the meridional fractures of the Arctic and Antarctic which were generated by the epeirogenetic centers of the North and South Poles, and thereby offering a convincing demonstration of the constancy of the earth's axis of rotation during the past 200 million years, categorically denied the possibility that the poles could have deviated by any great amount from their present position.

E. Dzh. Epik (1957) considers it an established fact that the relative positions of the poles and continents have not basically changed during the past 100 million years. Epik believes, in fact, that we can assume the relative constancy of the poles and continents back to the Cambrian (500 million years) as a reliable working hypothesis. A different hypothesis would entail serious difficulties in explaining glacial epochs more ancient than the Permian-Carboniferous.

On the basis of a conclusion reached from studying the biological productivity of the equatorial zone of the ocean, the equator has remained in a single position for 500 million years: according to this, the axis of rotation must have remained fixed for the whole of the Paleo-Meso-Cenozoic. This conclusion was presented at the First International Oceanographic Congress, held in New York in 1959.

On the other hand, the results of paleomagnetic studies have led to the conclusion that during the Paleozoic both the geographic and the magnetic /119 poles were in the equatorial zone. However, the data obtained for the paths supposedly followed by the poles in the various continents are very contradictory (P. N. Kropotkin, 1960), and the necessity of resolving the contradictions has led certain geologists to restore the mobilistic concepts of A. Wegener, though the aphysical and antistructural character of the latter has long been demonstrated by a number of writers. In processing paleomagnetic data, we have failed essentially to take into account the effects of differential zonal shift, and of the twisting of entire continents--phenomena which have been established both on the basis of empirical data (Li, Sy-Guan, 1939, 1955; P. S. Voronov, 1959 c) and theoretical considerations. An important consequence of these planetary effects is found in the S-shaped twisting of the paleogeographic and paleomagnetic meridians. This twisting would grow in the course of time, possibly giving the *apparent* effect of a shifting of the paleomagnetic poles: generally speaking, this effect would be more prominent the older the rock sample taken.

The seriousness of the objections raised against the stability of the geographic poles by paleogeographers who have established the disparity between the ancient climatic zones and the modern ones (for instance, the hot climate which present-day polar lands during the Cretaceous and the Paleogene), has been considerably mitigated by the work of P. P. Predtechenskiy (1948), who studied this phenomenon in connection with variations in solar activity. Still, on the basis of the studies made by a great many investigators, beginning with P. Reibisch (1901, 1905) and H. Simroth (1907) and ending with N. M. Strakhov (1960), one must conclude that some degree of relative displaement of the equator must have taken place. Here the characteristic fact is that the points of intersection between the supposed ancient equators and the modern one lie where the minor equatorial axis cuts through onto the terrestrial surface ($\phi = 0°$, $\lambda = 105 - 75°$).

This curious fact can be treated as the result of wobbling of the asymmetrical-triaxial terrestrial ellipsoid around the minor equatorial axis. In such a case, the indicated centers would acquire the role of special "poles of wobbling", while the meridian circle of the major equatorial axis, 15 - 165°, might be called the "circle of wobbling." The cause of the phenomenon evidently consists in a shift of the position of the body of the planet /120 *with respect to the axis of rotation*, resulting from asymmetrical redistribution of its masses during the formation of the continental and oceanic hemispheres of the earth. From what has been said, it follows that the hemispheres referred to are the *northeastern*, with pole in Europe (45° N, 15° E), and the southwestern, with pole in the Circum-Antarctic and Pacific Oceans, east of New Zealand (45° S, 165° W).

Mountainous features on the face of our planet are significantly more local in character than continents and oceans. The folds and breaks occurring in the lithosphere in connection with orogenesis exist on a compara- /121 tively small scale. They are, therefore, much more accessible to analysis, both in space and time, and have in fact been better studied, than the incomparably more extensive and slower processes accompanying the formation of oceans and continents.

In comparing the various continents one can establish a number of remarkable developmental patterns (Table 7). The graphic expression of these patterns (Figures 37 and 38) leads immediately to the following relationship: *the smaller the specific gravity of a continent, the thicker it is, the higher it is, the larger is its area, and the more complex are its mountain systems.* Such is the basic law of development of the major forms of terrestrial relief.

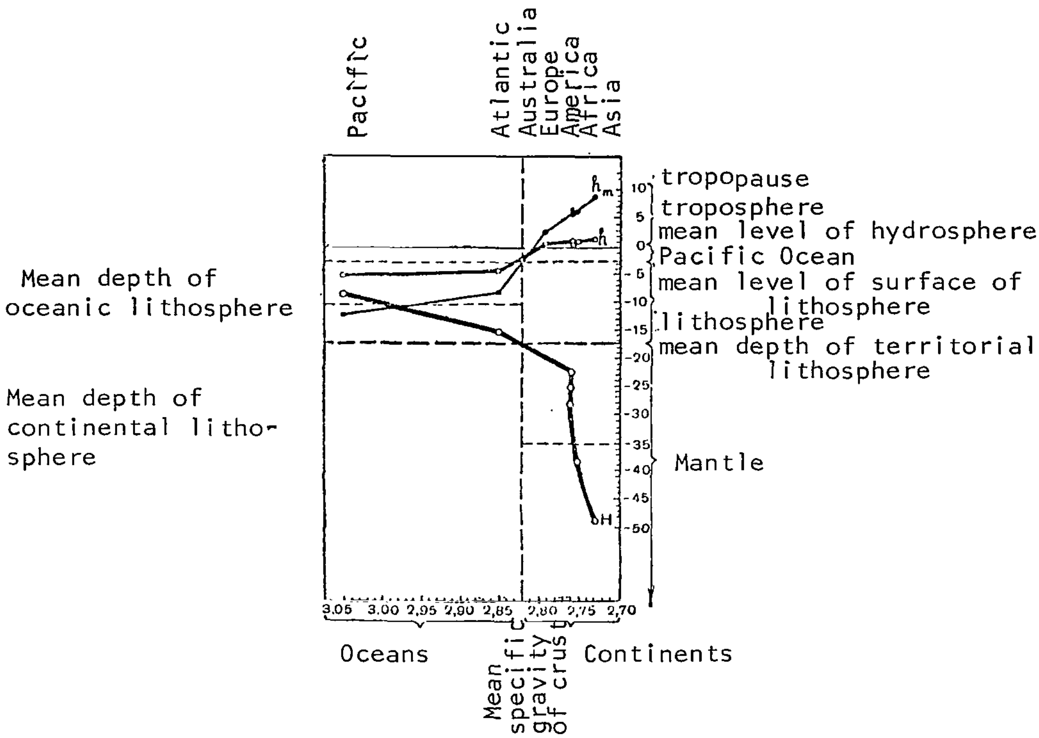


Fig. 37. Relationship Between the Thickness and the Height of Planetary Structures of the Earth's Crust, On the One Hand, and Their Density, On the Other. H - Thickness; h - Mean Height (Depth); h_m - Maximal Height (Depth).

A partial exception to this general rule is found in the case of the earth's highest continent-Antarctica. The area of this continent (not counting the glaciers of the continental shelf) is 13.1 million square kilometers; its mean altitude is 2,550 - 2,600 meters; its highest point (in the Queen Maud Range) is 5,180 meters above sea level; and the thickness of its lithosphere is 40 kilometers. The anomalously high mean altitude of Antarctica is explained by the thick continental glaciation of the continent. /123

The data of historical geology demonstrate convincingly that *during the early stages of development, the surface of the earth was characterized by the presence of shallow seas and low elevations of dry land, including low altitude of mountains. Subsequent development led to increase in the granitic foundation of the continents, both in the vertical and in the horizontal directions, to sinking of the Mohorovicic discontinuity, to increase in dry-land area, to reduction in the dismemberment of the continents, to reduction in the area of the oceanic type of lithosphere, to deepening and increased*

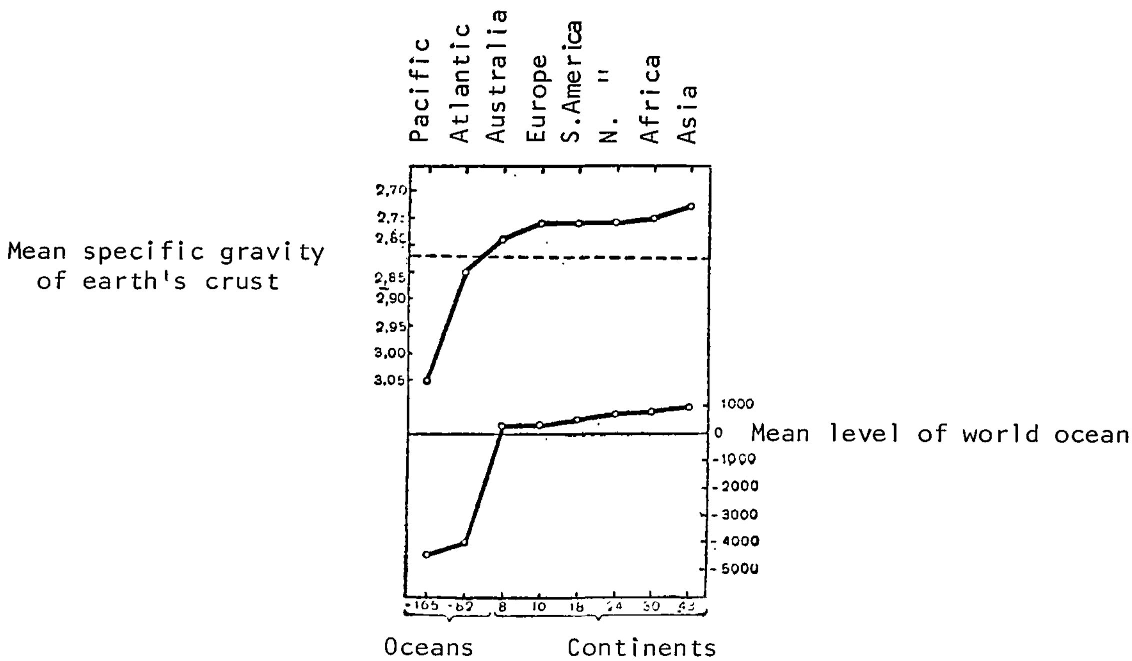


Fig. 38. Relationship Between the Area of the Ocean Floor and Of The Continents, On the One Hand, and Their Specific Gravity, On the Other. The Relationship Between Area and the Height (Depth) of Major Forms of Terrestrial Relief.

volume of the oceans, and, finally, to a general increase in the contrast of relief. In Figure 39 is shown the hypothetical course of change in the hypsographic curve of the earth, in support of this basic conclusion.

One interesting feature of the historical development of the earth is that the process of filling the oceanic troughs with water, in general proceeded parallel with the process of formation of those oceans, being marked by only a few deviations in one direction or the other--the two processes were occasionally out of balance. This means that the volume of surface waters during the history of the earth, with some irregularities, has on the whole continued to increase. This balance in the increase of surface waters and in the capacity of the oceanic troughs becomes understandable when we consider that the only motive force of tectonic development is *gravity*, which, on the one hand, leads to uneven gravitational compression of the earth, and, on the other, to differentiation of the material of the planet.

In summary, then, we can say that, for the surface features of the earth, the following two plans of origin are prominent: 1) zonal, asymmetrical with respect to the equatorial plane; and 2) a second plan which is

TABLE 7. Structural Characteristics of the Major Forms of Terrestrial Relief

(See next page for footnotes)

Continent or Ocean	Area (in millions of Square Kilometers)	Mean Altitude or Depth, in Kilometers (According to E. Kossinna, 1933)	Greatest Altitude or Depth, in Meters	Mean Thickness of Lithosphere, in Kilometers	Mean Density of Lithosphere, in gr/cm^3 (According to B.F. Bonchkovskiy (1953)	Longitudinal Geoidal Waves, Characterizing Modern Triaxiality of the Figure of the Earth, in Meters (According to I. D. Zhongolovich, 1952)
Asia	43.4	0.960	8,847, Everest[1]	50	2.73	-160 Australoasiatic Sector
Africa	30.3	0.750	5,895, Kilimanjaro	39	2.75	+136 Eurafrican Segment
North America	24.5	0.720	6,187, Mackinley	29	2.76	-97 (American Sector)
South America	18	0.590	6,960, Aconcagua	26		
Europe	10	0.340	5,633, El'brus	23	2.76	
Australia	7.7	0.340	2,239, Kosciusko		2.79	
Atlantic Ocean	82.4	-3.926	-9,218 in Puerto Rican Trough	15	2.85	
Pacific Ocean	165	-4.282	-11,521, in Mariana Trough[2]	8[3]	3.05	+120 (Pacific Segment)

Footnotes to Table 7:

[1] According to studies made in India during the fifties (Atlas *Die Erde*, VEB Hermann Haack, Gotha, 1960). The earlier value for the altitude of Everest, 8,882 meters, which still appears in textbooks and the popular literature, must be considered obsolete.

[2] This is the greatest known depth of the Pacific Ocean, reached by bathysphere on 23 January 1960.

[3] From the islands of Japan to California.

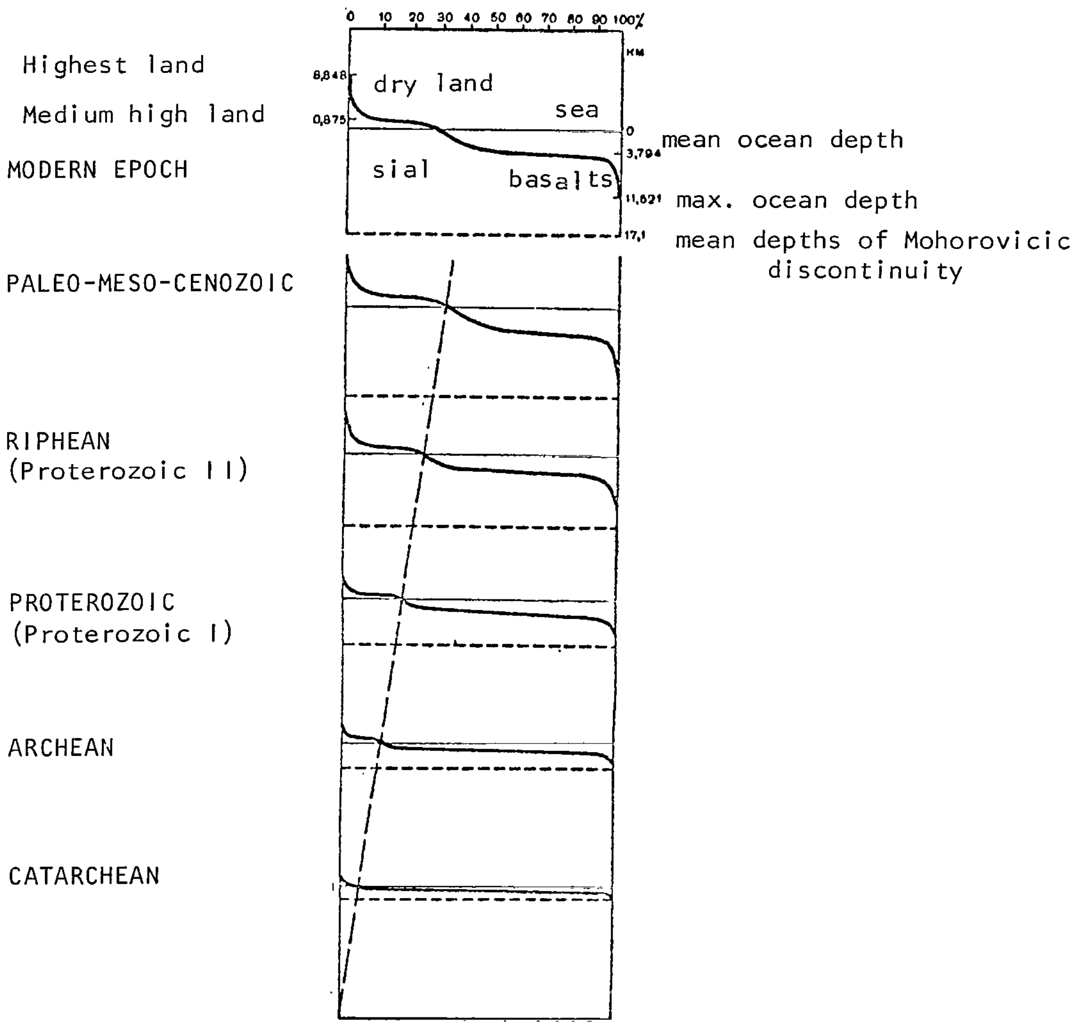


Fig. 39. Suggested Scheme of Variations in Dry-Land Altitudes, Ocean Depths, the Hypsographic Curve, and the Depth of the Mohorovicic Discontinuity During Geological History.

present in two aspects--a) asymmetrical with respect to the plane of the meredian 15 - 165°, and b) segmental-submeridional-meridional, and asymmetrical with respect to the plane of the meridian 105 - 75°. As a result of /125 the superimposition and interaction of these two planes, the existing form of the earth's surface has taken shape.

The fact that the overall global morphological plan of the earth has been preserved from the most ancient times up to our own era is explained by the circumstance that the major forms of relief which are denuded are constantly renewed by repeated, and compensatory, movements of the lithosphere (Figure 40). These movements are the derivatives of still other movements in the atmosphere-hydrosphere, and of abyssal processes taking place within the mantle and core of the earth.

On the basis of available data on the mean rate of denudation for the entire earth (D. Gilluli, 1955), one can assume that the mean rate of such planetary turnover of material (during the modern epoch) amounts to 1 millimeter a year, or 10 centimeters a century.

Regulated by the intensity of denudation, this circulation of material depends substantially upon the action of rivers, winds and glaciers, being retarded or accelerated depending upon their degree of erosion.

The secular turnover of abyssal and surface substance may be of great significance in achieving the systematic loading of the terrestrial depths with solar energy with the help of "geochemical accumulators"--oxides of aluminum, kaolinite, coal, and other mineral formations. As N. V. Belov (1952) and V. I. Lebedev (1954) have pointed out, these minerals, formed on the surface of the earth under conditions of weathering, absorb and accumulate solar energy. When they sink into the depths of the earth, the crystal lattice of these minerals is reconstructed, and the energy they contain is liberated. The geochemical accumulators which are introduced into the closed system of secular circulation of terrestrial material, are first charged with solar energy on the surface branch of turnover, then transfer that energy to great depths (to the subcrustal portion of the turnover), where they are discharged.

Thus, solar energy is the energy of exogenic processes; it is expended in the weathering and the formation of systematic rocks, and it is systematically transferred into the depths of the earth, where, supplementing the energy of gravitational compression, it enters into magmatic, tectonic, and planetary-morphological processes. It is important to observe, as follows /127 from the work of P. P. Predtechenskiy (1948), M. S. Eygenson (1954) and D. G. Panov (1955 a), that the climatic and geomorphological conditions of weathering--and hence also the rate of accumulation of solar energy by the geochemical accumulators--vary depending upon the general oscillations in the intensity of atmospheric-hydrospheric circulation on the earth which result from variations in solar activity.

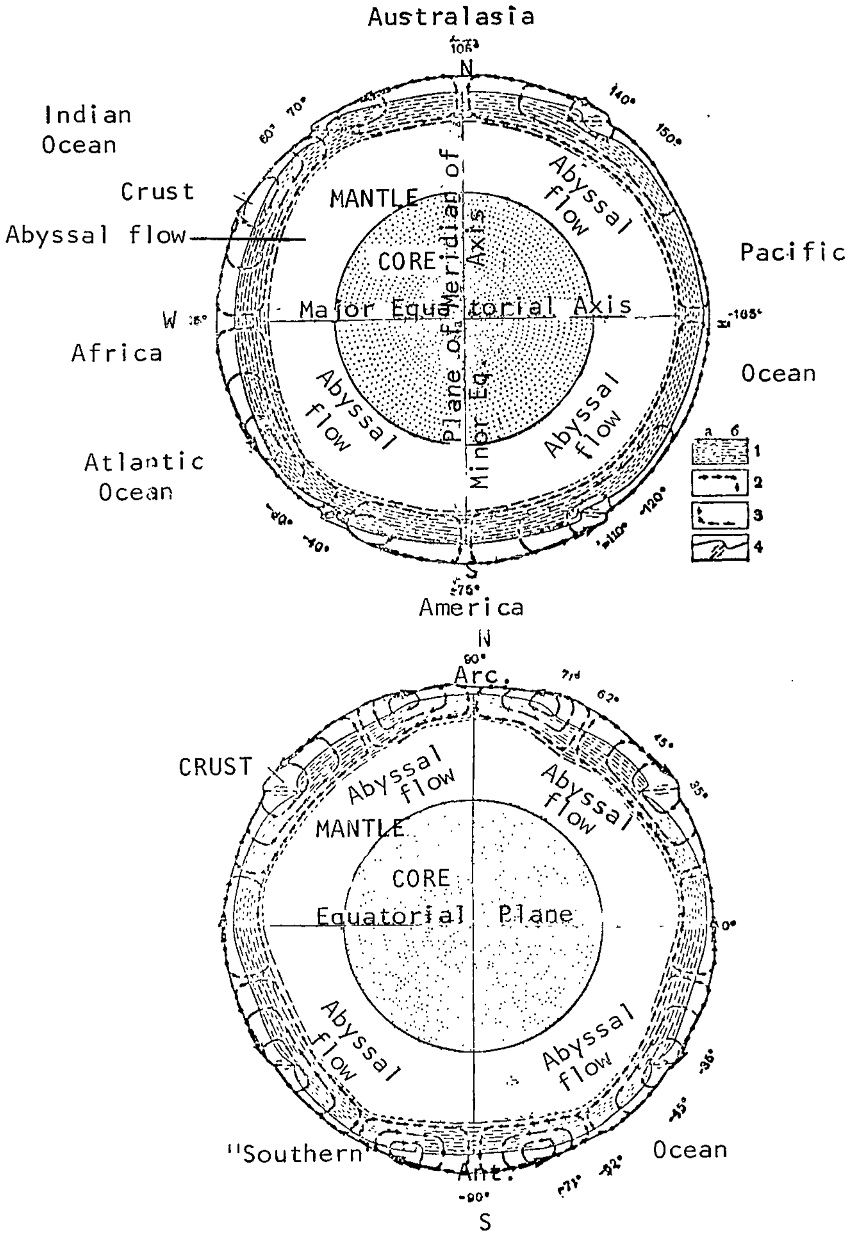


Fig. 40. Scheme of the General Secular Turnover of Material Affecting the Mantle, Lithosphere and Atmosphere-Hydrosphere of the Earth: 1 - Zone of Minimal Viscosity and Abyssal Differentiation of the Substance of the Mantle; 1 a - Segment and Belts of Increased Pressure Within the Mantle (Regions of Retardation of Differentiation Process; 1-b - Segment and Belts of Reduced Pressure Within the Mantle (Regions of Acceleration of Differentiation

Continued on next page...

Key to Figure 40 Concluded:

Process); 2 - Destruction and Subsidence; 3 - Abyssal Counterflow and Isostatic Uplift; 4 - Regions of Development of Shearing Stresses, Abyssal Fractures, Overthrusts, and Associated Earthquakes, Volcanic Phenomena, and Foredeeps.

Thereby the tectonic development of the earth, through a planetary secular exchange of abyssal and surface material, global cycles of sedimentation and solar-conditioned changes in the intensity of atmospheric-hydrospheric circulation, is closely tied in with solar activity and with its periodic variations.

Creation, destruction and re-creation (but always in connection with the build-up of irreversible changes, so that the process is never qualitatively or quantitatively the same)--such is the cycle (spiral would be a better term) of the tectonic development of our planet. The spring which activates this cycle is the internally contradictory process of gravitation, which involves the interaction of both attractive and repulsive forces. Attraction is accompanied by the acceleration of axial rotation; repulsion by the deceleration of that rotation. Since compression of the earth predominates over its expansion, while irreversible changes predominate over reversible ones, the overall process of geological development is not only cyclical but directional.

Thus, *the sciences of tectonics and earth morphology must first of all concern themselves with gravitation and the axial rotation of our planet; they cannot be approached without considering the earth's ties in space, first of all with the moon and the sun.*

* *
*

The time is not very far distant when astronautical expeditions from the earth will be extended to the surface of the moon, Mars and Venus, where detailed planetological investigations will be made. In these new worlds, which still are largely mysterious to us, we shall probably discover new minerals and organic compounds formed under conditions different from those on earth. But at least we know that the chemical elements found there are just the same as we have here at home. And will these planets turn out to be similar to earth in other respects as well? Probably they will. We should expect that the zonal distribution of oceanic subsidences and mountain belts on these planets, particularly Venus (whose surface is constantly hidden by a cloud cover), will be basically much the same as that of the earth and Mars (which, of course, we can see). In other words, the mountain belts of Venus, like our own, should be disposed in the zones of the parallels 35° N and 35° S, and the Southern Hemisphere of that planet should be more oceanic in character than the Northern Hemisphere. /128

The enormous prognostic value of the discovery of the critical parallels and meridians--apparently made in the interest of pure science--serves as the very best reply to the question one could hear until very recently--What is the use of any sort of theoretical investigation which is without an immediate utilitarian purpose?

APPENDIX I

THE EARTH: ITS MASS, DIMENSIONS AND OTHER RELATED QUANTITIES

Quantity	Unit of Measurement	Symbol	Numerical Value	Sources; Remarks[1]
Mass	Proportion of the mass of the sun	M	$5.9763 \cdot 10^{27}$ 1/331950	I.D. Zhongolovich, 1952
Major Orbital semi-axis	Astr. Unit in km	a_{orb}	149,457,000 1.000000	1961 data of Soviet radar determinations
Distance from sun at perihelion	a.u.	r_{π}	0.983298	for 1962
Distance from sun at aphelion	a.u.	r_{α}	1.016744	for 1962
Moment of perihelion passage		T_{π}	Jan.2, $4^{hr}52^{m}$	for 1962 USSR Astron.Yearbook for 1962
Moment of aphelion passage		T_{α}	Jul 4 5^{h} 05^{m}	for 1962
Siderial rotation period around sun	sec	P_{orb}	$31.558 \cdot 10^{6}$	
Mean rotational velocity	km/sec	U_{orb}	29.8	
Mean equatorial radius	km	$\bar{a}$	6,378.245 6,378.077	A. A. Izotov, 1950 I. D. Zhongolovich, 1956

[1] The source does not indicate whether the value given is generally accepted or has merely been calculated by the author.

APPENDIX I (Continued)

Quantity	Unit of Measurement	Symbol	Numerical Value	Sources; Remarks
Mean polar compression		α	1/298.3	A. A. Izotov, 1950
			1/296.6	I. D. Zhongolovich, 1952
			1/298.2	D. G. King-Hele, R. Merson, 1959. On observations on the movements of artificial earth satellites.
Difference in equatorial and polar semi-axes	km	$a - c$	21.382	A. A. Izotov, 1950
			21.500	I.D. Zhongolovich, 1956
Compression of meridian of major equatorial axis		α_a	1/295.2	I. D. Zhongolovich, 1952
Compression of meridian of minor equatorial axis		α_b	1/298.0	I. D. Zhongolovich, 1952
Equatorial compression		ε	1/30 000	A. A. Izotov, 1950
			1/32 000	I. D. Zhongolovich, 1952
Difference in equatorial semi-axes	m	$a - b$	213	A. A. Izotov, 1950
			199	I. D. Zhongolovich, 1952
Meridian of longitude of minor equatorial semi-axis		λ_a	15° E -	A. A. Izotov, 1950
			6° W	I. D. Zhongolovich, 1952
Meridian of longitude of minor equatorial axis		λ_b	105° E - 75° W;	A. A. Izotov, 1950
			84° E - 96° W	I. D. Zhongolovich, 1952

/130

Appendix I (Cont'd)

Quantity	Unit of Measurement	Symbol	Numerical Value	Sources; Remarks
Difference in polar semi-axes	m	$c_N - c_S$	~ 70 <100	I. D. Zhongolovich, 1952 Based on observations of artificial satellites[1]
Polar asymmetry		η	$\sim 1 \cdot 10^{-5}$	
Mean acceleration of gravity at equator		g_e	978, 057.3	I. D. Zhongolovich, 1952
Mean acceleration of gravity at poles	milligals (mgl)	g_ρ	983,225.1	
Difference in acceleration of gravity at pole and at equator		$g_\rho - g_e$	+5,167.8	
Difference in acceleration of gravity at equator	mgl	$g_a - g_b$	+30.2	I. D. Zhongolovich, 1952
Difference in acceleration of gravity at poles		$g_N - g_S$	+30	I. D. Zhongolovich, 1952
Mean acceleration of gravity for entire surface of terrestrial ellipsoid	mgl	g	979,783.0	I. D. Zhongolovich, 1952

[1] On the basis of materials published in Astron. J., Vol. 64 No. 1272, 1959.

/131

Appendix I (Cont'd)

Quantity	Unit of Measurement	Symbol	Numerical Value	Sources, Remarks
Mean radius	km	R	6,370.949	
Area of surface	km^2	S	$510.0501 \cdot 10^6$	
Volume	km^3	V	$1,083.1579 \cdot 10^9$	
Mean density	gr/cm^3	δ	5.5170	I. D. Zhongolovich. 1952
Siderial rotational period	sec	P	86,164.09	
Angular rotational velocity	rad/sec	ω	$7.292116 \cdot 10^{-5}$	
Mean equatorial Rotational velocity	km/sec	v	0.465	
Ratio of centri- fugal force to attractive force at equator		q	$\frac{1}{289}$	
Ratio of centri- fugal force to force of gravity at equator		q_e	$0.0034677 = \frac{1}{288}$	I. D. Zhongolovich, 1952
Coefficients chara- cterizing the radial distribution of densities within the earth		κ_1 κ	0.966 0.331	Based on observations of arti- ficial satellites; several larger values were given earlier[1]

[1] On the basis of materials published in the Astron. J., Vol. 64, 1272, 1959.

/132

Quantity	Unit of Measurement	Symbol	Numerical Value	Sources; Remarks
Radius of inertia	km; proportion of mean radius	R_i	3,674.735 0.5768	
Geocentric latitude of inertial parallel		ϕ_i	54°47'	
Moment of inertia	$gr \cdot cm^2$	I	$8.070 \cdot 10^{44}$	
Moment of rotation	$gr \cdot cm^2/sec$	L	$5.885 \cdot 10^{40}$	
Relative true secular braking of earth's rotation due to tidal friction		$\frac{\Delta\omega_e}{\omega}$	$-4.2 \cdot 10^{-8}$ per century	
Relative proper secular acceleration of earth's rotation		$\frac{\Delta\omega_i}{\omega}$	$+1.4 \cdot 10^{-8}$ per century	N. N. Pariyskiy, 1955
Relative observed secular braking of earth's rotation		$\frac{\Delta\omega}{\omega}$	$-2.8 \cdot 10^{-8}$ per century	
Mean rotational velocity of terrestrial radius due to abyssal compression	cm/century	$\frac{\Delta R}{\Delta t}$	~ 5 4.5 Assumed invariability of mass (M) and distribution of masses (κ)	B. Meyermann, 1928, 1928a; N. N. Pariyskiy, 1955

/133

Quantity	Unit of Measurement	Symbol	Numerical Value	Sources; Remarks
Secular variation in potential gravitational energy of earth accompanying reduction of terrestrial radius by 5 cm and corresponding increase in earth's kinetic energy	erg/century	ΔE	$\sim 17 \cdot 10^{30}$	Assumed uniformity of compression of entire planet. P. N. Kropotkin, 1948 and A. T. Aslanyan, 1955
Probable value of total energy of tectonic deformation of earth	erg/century	E_t	$\sim 1 \cdot 10^{30}$	With allowance for earthquakes, volcanic eruptions and other forms of tectonic activity P. N. Kropotkin, 1948
Secular loss of heat of earth through radiation into space	erg/century cal/century	$\Delta' E_k$	$1 \cdot 10^{30}$ $2.4 \cdot 10^{22}$	P. N. Kropotkin, 1948
Portion of earth's kinetic energy transformed into heat as a result of lunar and solar tides in the hydrosphere	erg/century cal/century	$\Delta'' E_k$	$0.11 \cdot 10^{30}$ $0.26 \cdot 10^{22}$	Heiskanen, 1922 and de Sitter, 1927
Difference in duration of days in March and August	sec	ΔP	0.0025 (March-Aug.)	N. N. Pariyskiy, 1955

/134

Quantity	Unit of Measurement	Symbol	Numerical Value	Sources; Remarks
Corresponding relative annual variation in earth's rotational velocity		$\frac{\Delta^* \omega}{\omega}$	$2.9 \cdot 10^{-8}$ (Aug.-March)	N. N. Pariyskiy, 1955
Presumed variation in earth's radius between August and March	cm	$\Delta^* R$	-9.2 Aug.-March)	
Annual variation in level of world ocean	cm	Δh_0	~10 (Sept.-March)	N. N. Pariyskiy, 1955

/135

Appendix II

The Earth's Lithosphere, Hydrosphere, Atmosphere and Biosphere

Quantity	Unit of Measurement	Symbol	Numerical Value	Source
Area of continents	km^2; in % of area of surface of earth	S_C	$149 \cdot 10^6$ 29.2	E. Kossina, 1933
Area of world ocean	km^2; in % of area of sur face of earth	S_o	$361 \cdot 10^6$ 70.8	E. Kossina, 1933
Mean height of continents above sea level	m	h_C	875	E. Kossina, 1933
Mean depth of world ocean	m	h_o	≈ 3794	Morskoy Atlas, Vol. II, 1953
Mean position of earth's surface with respect to sea level	m	h_m	≈ 2430	E. Kossina, 1933
Mean thickness of lithosphere within the limits of the continents	km	$h_{c.l.}$	35	M. Yuing and F. Press, 1955
Mean thickness of lithosphere within the limits of the ocean	km	$h_{o.l.}$	4.7	Kh. Khess, 1955
Mean rate of thickening of continental lithosphere	$m/10^6$ yr	$\frac{\Delta h}{\Delta t}$	10 - 40	V. I. Popov, 1955

/136

Appendix II (Cont'd)

Quantity	Unit of Measurement	Symbol	Numerical Value	Source
Mean rate of horizontal extension of continental lithosphere	km/10^6 yr	$\frac{\Delta l}{\Delta t}$	0.75 - 20	V. I. Popov, 1955
Mass of lithosphere	gr	m_l	$2.367 \cdot 10^{25}$	A. Poldervart, 1955
Amount of water released from the mantle and core in the course of geological time	gr		$3.400 \cdot 10^{24}$	Kalp, 1951
Total reserve of water in the mantle	gr		$2 \cdot 10^{26}$	A. P. Vinogradov, 1959
Present day content of free and bound water in the earth's lithosphere	gr		$2.2 - 2.6 \cdot 10^{24}$ $1.8 - 2.7 \cdot 10^{24}$	Kalp, 1951 A. Poldervart, 1955
Mass of hydrosphere	gr	m_h	$1.664 \cdot 10^{24}$	A. Poldervart, 1955
Amount of oxygen bound in the earth's crust	gr		$1.300 \cdot 10^{24}$	A. Poldervart, 1955
Amount of free oxygen	gr		$1.5 \cdot 10^{21}$	A. Poldervart, 1955
Mass of atmosphere	gr	m_a	$5.136 \cdot 10^{21}$	A. Poldervart, 1955
Mass of biosphere	gr	m_b	$1.148 \cdot 10^{19}$	A. Poldervart, 1955

/137

Quantity	Unit of Measurement	Symbol	Numerical Value	Source
Mass of living matter in the biosphere	gr		$3.6 \cdot 10^{17}$	A Poldervart, 1955
Density of living matter on dry land	gr/cm^2		0.1	A. Poldervart, 1955
Density of living matter in ocean	gr/cm^3		$15 \cdot 10^{-8}$	A. Poldervart, 1955

/138

Appendix III

Object of Study	Age in billions of years	Source
Fossils of the most ancient organisms	2.7	L. Arens, 1955
Most ancient known terrestrial rocks:		
Mica (biotite) found within migmatites on the Kola Peninsula and at the Great Rapids of the Voron'ya River in 1958;	3.6	A. A. Polkanov and E. K. Gerling, 1961
Rock found in South Africa	4	A. L. Heils, 1960[1]
Lithosphere	~ 4	V. I. Baranov, 1958
Earth	~ 5	A. P. Vinogradov, 1959 and others

[1] See *Priroda*, No. 11, 1960, p. 113.

Appendix IV

Approximate Scale of Geologic Time[1], Based on the Data of Soviet Research, 1960.

Era		Period or Epoch	Beginning and end, in millions of years	Approximate Duration, in millions of years		
Paleo-Meso-Cenozoic	Cenozoic	Quaternian				
		Contemporary	0 - 10,000 yrs ± 2,000 yrs	8 - 12,000 yrs		570
		Pleistocene	10,000 - 1,000,000 yrs ± 50,000 yrs	1		
		Tertiary				
		Pliocene	1 - 10	9	69	
		Miocene	10 - 25	15		
		Oligocene	25 - 40	15		
		Eocene	40 - 60	20		
		Paleocene	60 - 70	10		
	Mesozoic	Cretaceous	70 - 140	70		
		Jurassic	140 - 185	45		
		Triassic	185 - 225	40		
	Paleozoic	Permian	225 - 270	45		
		Carboniferous	270 - 320	50		
		Devonian	320 - 400	80		
		Silurian	400 - 420	20		
		Ordovician	420 - 480	60		
		Cambrian	480 - 570	90		

1 Based on the geochronological scale of the Commission for Determining the Absolute Age of Geological Formations, published in *Izv. AN SSSR*, geological series, No. 10, 1960.

Appendix IV continued on next page..

Appendix IV (Concluded)

Era	Period or Epoch	Beginning and end, in millions of years	Approximate Duration, in millions of years
Pre-Cambrian IV (Riphean)[1]		570 - 1,200	630
Pre-Cambrian III (Proterozoic)[2]		1,200 - 1,900	700
Pre-Cambrian II (Archean)		1,900 - 2,700	800
Pre-Cambrian I (Catarchean)		2,700 - 3,500	800
Pregeological era		3,500 - 5,000	1,500

[1] Proterozoic II.

[2] Proterozoic I.

REFERENCES

1. Appel', P. (1921) [1]"*Figury ravnovesiya vrashchayushcheysya odnorodnoy zhidkosti,*" [Equilibrium Figures of a Rotating Homogeneous Liquid], Moscow-Leningrad, 1936.
2. Arabyu, N. (1937), "On Deformation of the Earth,", *Proceedings of the Seventh Session of the International Geological Congress,* Vol. II, Moscow, 1939.
3. Arens, L. Kh. (1955), "The Most Ancient Rocks Discovered on Earth," *The Earth's Crust,* Moscow, 1955.
4. Aslanyan, A. T., "A Study in the Theory of Tectonic Deformation," Yerevan, 1955.
5. Afanas'yev, G. D., "On the Problem of Granite, Part 2," *Izv. AN SSSR, ser. geol.,* No. 1, 1953.
6. Baranov, V. I., "Recent Data on the Absolute Age of the Earth," *Voprosy kosmogonii, Questions of Cosmogony,* Vol. VI, Moscow, 1958.
7. Belov, N. V., "Geochemical Accumulators," *Proceedings of the Institute of Crystallography, USSR Academy of Sciences,* No. 7, Moscow, 1952.
8. Belousov, V. V., "General Geotectonics," Moscow-Leningrad, 1948.
9. Belousov, V. V., " Basic Problems of Geotectonics," Moscow, 1954.
10. Belousov, V. V., "Foremost Problems in General Geotectonics," *Soviet Geology, Collection 41,* 1954a.
11. Belousov, V. V., "Internal Structure and Development of the Earth in the Light of Geotectonic Data," *Proceedings of the Geophysical Institute, USSR Academy of Sciences,* No. 26, p. 153, Moscow, 1955.
12. Belousov, V. V., "The Development of the Terrestrial Sphere and Tectogenesis," *Sov. geologiya,* No. 7, 1960.
13. Bemmelen, R. V. (1954), "Mountain Formation," Moscow, 1956.
14. Ben'of G. (1955), "Seismic Data on the Structure of the Crust and Tectonic Activity," *The Earth's Crust,* Moscow, 1957.
15. Berg, L.S., "Natural Features of the USSR," 3rd Ed., Moscow, 1955.
16. Bonchkovskiy, V. F., "Internal Structure of the Earth," Moscow, 1953.
17. Bubnov, S., " Basic Problems of Geology," Moscow-Groznyy-Leningrad-Novosibirsk , 1934.
18. Bacon, Francis, "A New Organon, or the True Rules for the Understanding of Nature," *Collected Works of Francis Bacon, Vol. 2,* St. Petersburg, 1874.
19. Bykhanov, Ye. V., "Astronomical Prejudices and Materials for Devising a New Theory of the Origin of the Solar System," Livna, 1877.
20. Bykhanov, Ye. V., "Something About Celestial Mechanics,"Livna, 1894.
21. Wegener, A. (1951), "The Rise of Continents and Oceans," Moscow, 1925.
22. Vinogradov, A. P., "Chemical Evolution of the Earth," Moscow, 1959.
23. Voyeykov, A. I., "Physical Geography of the Earth," *The Brockhaus-Efron Encyclopedic Dictionary,* Vol. 12, p. 23, St. Petersburg, 1894.
24. Voronov, P. S., "The Structural Scheme of Antarctica," *Information Bulletin of the Soviet Antarctic Expedition,* No. 1, Leningrad, 1958.

---

[1] In this list, dates in parentheses immediately following the author's name indicate the year of publication of the first edition in the original language.

25. Voronov, P. S., "On the Supposed Zone of Buried Block Structures in the Eastern Antarctic, Between the South Pole and Olaf-Prydz Bay," *op. cit.* No. 4, Leningrad, 1959.
26. Voronov, P. S., "The Geological Significance of the Mantle of the Young Mountains South of the Prince Charles Chain in Eastern Antarctica," *op. cit.*, No. 5, Leningrad, 1959a.
27. Voronov, P. S., "Symmetrical Sectorial Character of the Distribution of the Main Forms of Macrorelief in the Arctic and Antarctic, in Relation to the Block Structure of the Earth," *op. cit.*, No. 16, Leningrad, 1959a.
28. Voronov, P. S., "Tangential Stresses and Crustal Displacement Deformations North of Central Siberia," *op. cit.*, No. 17, Leningrad, 1959c.
29. Voronov, P. S., "On the Structure of the Antarctic," *Proceedings of the Scientific-Research Institute of Arctic Geology*, Vol. 113, No. 2, Leningrad, 1960.
30. Voronov, P. S., "On the Likelihood of the Effect of Terrestrial Rotational Forces on the Dispostion of Major Meso-Cenozoic Fractures in the Arctic and Antarctic," *Third Astrogeological Conference on Problems in the Theory of the Earth, Abstracts of Reports*, Leningrad, 1960a.
31. Voronov, P. S. and A. Ya. Krylov, "The Age of the Most Ancient Rocks of the Antarctic," *Information Bulletin of the Soviet Antarctic Expedition*, No. 28, Leningrad, 1961.
32. Gakkel', Ya. Ya., "The Submarine Lomonosov Range," *Around the World*, No. 11, 1954.
33. Gakkel', Ya. Ya., "Science and the Conquest of the Arctic", Leningrad, 1957.
34. Gakkel', Ya. Ya., "The Significance of Geophysical Observations Made With Artificial Earth Satellites in Polar and Subpolar Regions," *Probl. Arktiki i Antarktiki*, No. 6, 1960.
35. Gilluli, Dzh. (1955), "Geological Differences Between the Continents and the Oceanic Troughs," *The Earth's Crust*, Moscow, 1957.
36. Gregory, John Walter (1912), "The Formation of the Earth", Saint Petersburg, 1914.
37. Demenitskaya, R. M., "Planatary Structures of the Earth's Crust and Their Reflection in Bouguer Anomalies," *Sov. geologiya*, No. 8, 1958.
38. Demenitskaya, R. M., "A Method for Studying the Structure of the Crystalline Portion of the Earth's Mantle on the Basis of Geophysical Data," *Sov. geologiya*, No. 1, 1959.
39. Dzheffris, Kh. (1924), "The Earth: Its Origin, History and Structure," *Translated from the fourth English edition of 1959*, Moscow, 1960.
40. Dragunov, V. I., "Concerning the Trans-Siberian Transverse Dislocation," *Materials on the Geology and Commercial Minerals of the Siberian Platform", Main title: "Proceedings of the All-Union Scientific-Research Institute of Geology"*, No. 44, Leningrad, 1960.
41. Yefremov, Yu. K., "Classification of Relief-Shaping Factors in Connection with Problems of Geomorphological Charting," *Voprosy geografii*, Collection 36, Moscow, 1954.
42. Zharkov, V. N., "On the Problem of a Terrestrial Iron Core," *Dokl. AN SSSR*, Vol. 135, No. 6, 1960.

43. Zhongolovich, I. D., "The Earth's External Gravitational Field and the Basic Constants Associated with It," *Proceedings of the Institute of Theoretical Astronomy*, No. 3, Moscow-Leningrad, 1952.
44. Zhongolovich, I. D., "On Determining the Dimensions of the General Terrestrial Ellipsoid," *op. cit.*, No. 6, Moscow-Leningrad, 1956.
45. Zotov, P. P., "Are Gravitational Forces Heating up the Earth?," *Priroda*, No. 3, 1960.
46. Ivanov, A. A., "The Theory of Precession. A Dissertation for the Degree of Doctor of Astronomy and Geodesy," Saint Petersburg, 1899.
47. Izotov, A. A., "The Figure and Dimensions of the Earth as Determined by Modern Data," *Proceedings of the Central Scientific-Research Institute of Geodetics, Cartography and Aerial Photography*, No. 73, Moscow, 1950.
48. Karpinskiy, A. P. (1888), "On the Correctness of Our Ideas Concerning the Outlines, Distribution and Structure of the Continents," *Collected Works*, No. 73, Moscow, 1950.
49. Katterfel'd, G. N., "On the Nature of the Linear Formations on Mars," *Proceedings of the Astrobotany Sector of the Kazakh Academy of Sciences*, Vol. IV, Alma Ata, 1955.
50. Katterfel'd, G. N., "Basic Patterns of Planetary Relief," *Scientific Notes of the A. I. Gertsen State Pedagogical Institute (Leningrad)*, Vol. 151, Leningrad, 1958.
51. Katterfel'd, G. N., "Toward the Problem of the Tectonic Origin of the Linear Formations on Mars," *Transactions of the All-Union Geographic Society*, Vol. 91, No. 3, 1959.
52. Katterfel'd, G. N., "Symmetry and Asymmetry in the Structure of the Earth," *Third Astrogeological Conference on Problems in the Theory of the Earth. Abstracts of Reports*, Leningrad, 1960.
53. Katterfel'd, G. N., "Main Patterns in the Development of Terrestrial Topography," *Author's Abstract of Candidate's Dissertation*, Leningrad, 1961.
54. Kozlovskaya, S. V., "Toward the Problem of the Formation of the Surface Features of the Terrestrial Planets," *Geographical Collection XV (Astrogeology)*, Leningrad, 1962.
55. Kozlovskaya, S. V., "A Comparative Analysis of the Internal Structure and Composition of the Terrestrial Planets and Satellites," *Dokl. AN SSSR*, Vol. 92, No. 5, 1953.
56. Kozyrev, N. A., "Causal or Nonsymmetrical Mechanics in Linear Approximation", Pulkovo, 1958.
57. Kornfel'd, M., "The Elasticity and Strength of Liquids," Moscow-Leningrad, 1951.
58. Krasovskiy, F. N., "Modern Tasks and Development of Degree Measurements," *Izv. AN SSSR, ser. geogr. i geofiz.*, No. 3, 1941.
59. Kropotkin, P. N., "Basic Problems in the Energetics of Tectonic Processes," *Izv. AN SSSR, ser. geol.*, No. 5, 1948.
60. Kropotkin, P. N., "The Cosmogonic Theory of O. Yu. Schmidt, and the Earth," *Izv. AN SSSR, ser. geogr. i geofiz.*, No. 1, 1950.
61. Kropotkin, P. N., "Modern Geophysical Data on the Structure of the Earth, and the Problem of the Origin of Basaltic and Granitic Magma," *Izv. AN SSSR, ser. geol.*, No. 1, 1953.

62. Kropotkin, P. N., "Paleomagnetism and Its Significance in Stratigraphy and Geotectonics," *Izv. AN SSSR, ser. geol.*, No. 12, 1960.
63. Kyunen, F. (1955), "Sea Level and Earth Curves," *The Earth's Crust*, Moscow, 1951.
64. Paktionov, A. F. (1939), "The North Pole," Moscow, 1960.
65. Lebedev, V. I., "The Possibility of the Absorption of Solar Energy by the Crystalline Substance of the Earth," *Izv. AN SSSR, ser. geol.*, No. 4, 1954.
66. Levin, A. Yu., "The Composition of the Earth," *Proceedings of the Geophysical Institute, USSR Academy of Sciences*, No. 26 (153), Moscow, 1955.
67. Levinson-Lessing, F. Yu., "On Secular Shifts of Dry Land and Sea," *Scientific Notes of Yur'yev University*, No. 1, Yur'yev, 1893.
68. Levinson-Lessing, F. Yu., "Introduction to Geology," Petrograd, 1923.
69. Levinson-Lessing, F. Yu., "Petrography", 5th ed., Moscow-Leningrad, 1940.
70. Leonov, N. I., "New Ideas About the Horizontal Displacement of the Continents," Fergana, 1949.
71. Li, Hsü-Kuang (1939), "Geology of China," Moscow, 1952.
72. Li, Hsu-Kuang (1955), "Vortical Structures of Northwestern China," Moscow, 1958.
73. Lichkov, B. L., "Basic Pattern of Secular Rise and Subsidence in the Earth's Crust," *Priroda*, No. 4, 1941.
74. Lichkov, B. L., "Continental Shifts and Climate in the History of the Earth," Leningrad-Moscow, 1931.
75. Lichkov, B. L,, "Concerning the Rhythm of Changes of the Earth's Surface During Geological Time," *Priroda*, No. 4, 1941.
76. Lichkov, B. L., "Changes in Terrestrial Relief Viewed in Connection with Tectonics and Energy Balance (Toward a Description of Geological Space)," *Dokl. AN SSSR*, Vol. 44, No. 8, 1944.
77. Lichkov, B. L,, "The Structure of the Globe and the Major Forms of Its Relief," *Fourth Conference on the Geomorphology of the Trans-Caucasus*, Yerevan, 1953.
78. Lichkov, B. L., "Energetics of the Earth and the Cause of Tectonic Phenomena," *Geological Notes of the L'vov Geological Society*, No. 1, 1954.
79. Lichkov, B. L., "Climatic Periods, Geology and Fate of Life," *Proceedings of the Leningrad Society of Nature Lovers*, Vol. 71, No. 1, 1960.
80. Lichkov, B. L., "Natural Waters of the Earth and the Lithosphere," Moscow-Leningrad, 1960a.
81. Lichkov, B. L., and Ya. Ya. Gakkel', "The Second Conference on Problems of Astrogeology," *Izv. VGO*, Vol. 89, No. 2, 1957.
82. Lodochnikov, V. N., "Some General Problems Associated with Magma Yielding Basaltic Rocks," *Notes of the All-Union Mineralogical Sco Society*, Vol. 68, No. 2 - 3, 1939.
83. Lomonosov, M. V. (1763), "Concerning Terrestrial Layers," Lomonosov's *On the Layers of the Earth; Other Geological Studies*, Moscow, 1949.
84. Lomonosov, M. V. (1763a), "A Brief Description of Various Jouneys Along the Northern Seas; an Indication of a Possible Connection Between the Siberian Ocean and Eastern India, Sections 64 - 67," in *V. A. Perevalov's Lomonosov i Arktika (Lomonosov and the Arctic)*,

Moscow-Leningrad, 1949.
85. Lyustikh, Ye. N., "Concerning the "Cosmogeotectonic' Hypothesis," *Izv. AN SSSR, ser. geofiz.*, No. 2, 1956.
86. Lyustikh, Ye. N., "The Problem of the Energy Balance of the Earth in Geotectonic Hypotheses," *Izv. AN SSSR, ser. geofiz.*, No. 3, 1957.
87. Lyustikh, Ye. N., "A Critique of the Geotectonic Contraction Hypothesis," *Proceedings of the Institute of Geophysics, USSR Academy of Sciences*, No. 3, (170), 1958.
88. Magnitskiy, V. A., "On the Possible Character of Deformations in Abyssal Layers of the Earth's Crust and in the Subcrustal Layer,"*Bulletin of the Moscow Society of Nature Lovers, Geological Section*, Vol. 53, No. 2, 1948.
89. Magnitskiy, V. A., "Toward the Problem of the Density and Compressibility of the Earth's Shell," *Voprosy kosmogonii*, Vol. 53, No. 2, 1948.
90. Magnitskiy, V. A., "Principles of Geophysics," Moscow, 1953.
91. Magnitskiy, V. A., " Concerning the Physical State of Matter in Abyssal Portions of the Earth," *Proceedings of the Geophysical Institute, USSR Academy of Sciences*, No. 26, 1955.
92. Magnitskiy, V. A., "Toward the Problem of the Origin and Lines of Development of Continents and Oceans," *Voprosy kosmogonii*, Vol. VI, Moscow, 1958.
93. Magnitskiy, V. A., "Internal Structure of the Earth," Moscow,1961.
94. Maksimov, I. V., "On the 'Polar Tide' in the Earth's Oceans and Atmosphere," *Dokl. AN SSSR*, Vol. 86, No. 4, 1952.
95. Markov, K. K., "Basic Problems of Geomorphology,"Moscow, 1948.
96. Markov, K. K. (1951), "Paleogeography," 2nd ed., Moscow, 1960.
97. Mart'yanov, N. Ye., "Regions of Stretching in the Earth's Shell," *Dokl. AN SSSR*, Vol. 116, No. 6, 1957.
98. Men'ye, St. (1874), "Comparative Geology or Geology of Terrestrial Bodies," Saint Petersburg, 1896.
99. Neymayr, M., "History of the Earth," translated from the German, Saint Petersburg, 1899.
100. Nikolayev, N. I., "Development of the Structure of the Earth's Crust and Its Relief, Based on the Data of Geotectonics," *Sov. geologiya*, Collection 48, 1955.
101. Nikolayev, N. I., "A Study of the Most Recent Geological Stage of Crustal Development; the Significance of the Corresponding Data in Understanding Theoretical Problems of Geotectonics," *Bulletin of the Moscow Society of Nature Lovers, Div. of Geology*, Vol. 31 (61), No. 5, 1956.
102. Obruchev, V. A., "The Pulsation Hypothesis of Geotectonics," *Izv. AN SSSR, ser. geol.*, No. 1, 1940.
103. Orlov, A. Ya., "On the Triaxiality of the Earth," *Dokl. AN SSSR*, Vol. 43, No. 8, 1944.
104. Pavlov, A. P., "An Attempt to Understand the Pre-Archean Era of the Earth's History, and to Determine Its Influence on the Subsequent Evolution of the Geoid," *Bulletin of the Moscow Society of Nature Lovers, Div. of Geology*, Vol. 31, 1922.

105. Pavlovskiy, Ye. V., "Certain General Developmental Patterns of the Earth's Crust," *Izv. AN SSSR ser. geol.*, No. 5, 1953.
106. Panov, D. G., "Cosmic Influences in the Life of the Earth," *Izv. Vsesoyuz, geogr. o-va*, Vol. 78, No. 1, 1946.
107. Panov, D. G., "Concerning the Origin and History of the Oceans," *Voprosy geografii*, Collection 12, Moscow, 1949.
108. Panov, D. G., "Oceans and Seas in the Morphology of the Globe," Memories of L. S. Berg, *A collection of S'udies in Geography and Biology*, Moscow, Leningrad, 1955.
109. Panov, D. G., "On the Link Between the Tectonic History of the Earth and Solar Activity," *Scientific Notes of Rostov University*, No. 31, 1955a.
110. Panov, D. G., "Certain Geographical Conclusions Based on the Pulsation Theory of Geotectonics," *op. cit.*, Vol. 44, No. 8, 1959.
111. Pariyskiy, N. N., "Change in the Length of the Day, and Deformation of the Earth," *Astron. zhurnal*, Vol. 22, No. 2, 1945.
112. Pariyskiy, N. N., "Inconstancy of the Rotation of the Earth, and Its Deformation," *Proceedings of the Conference on Methods of Studying the Movements and Deformations of the Earth's Crust*, Moscow, 1948.
113. Pariyskiy, N. N., "Nonuniformity of the Earth's Rotation," *Proceedings of the Geophysical Institute, USSR Academy of Sciences, Geological Series*, No. 26 (153), Moscow, 1955.
114. Peyve, A. V., "Abyssal Fractures in Geosynclinal Regions," *Izv. AN SSSR, ser. geol.*, No. 5, 1945.
115. Peyve, A. V. and V. M. Sinitsyn, "Some Basic Questions in the Theory of Geosynclines," *Izv. AN SSSR, ser. geol.*, No. 4, 1950.
116. Poldervart, A. (1955), "The Chemistry of the Earth's Crust," *The Earth's Crust*, Moscow, 1957.
117. Polkanov, A. A. and E. K. Gerling, "The Geochronology and Geological Evolution of the Baltic Shield and Its Folded Frame," *Proceedings of the Laboratory of Pre-Cambrian Geology*, No. 12, 1961.
118. Popov, V. I., "History of the Depressions and Rises of the Western T'ien-Shan," Tashkent, 1938.
119. Popov, V. N., "Some Basic Assumptions of the Nuclear Theory of the Development of the Earth's Crust," *Scientific Notes of the Uzbek Division of the All-Union Mineralogical Society*, No. 7, Tashkent, 1955.
120. Popov, V. I., and O. A. Ryzhkov, "On the Counterclockwise Rotation of the Strikes of Variously Aged Formations," *Western Uzbek Division of the Mineralogical Society*, No. 7, Tashkent, 1955.
121. Predtechenskiy, P. P., "Climates of the Geological Past, and A Scheme Showing their Dependence Upon Variations in Solar Activity," *Proceedings of the Main Geophysical Observatory*, No. 8, (70), Leningrad, 1948.
122. Razbignaya, Ye. P., "On the Origin of the Moon." *Author's abstract of Candidate's Dissertation*, London, 1954.
123, Ramberg, G. (1955), "Thermodynamics and the Kinetics of Petrogenesis," *The Earth's Crust*, Moscow, 1957.
124. Rikhter, G. D., "Basic Features of the Orography of the Northern Polar Regions," *Izv. AN SSSR, ser. geol.*, No. 4, 1955.

125. Ronov, A. B. and V. Ye. Khain, "Devonian Lithological Formations of the World," *Sov. geologiya,* Collection 41, 1954.
126. Ronov, A. B. and V. Ye. Khain, "Carboniferous Lithological Formations of the World, *Sov. geologiya,* Collection 48, 1955.
127. Ronov, A. B. and V. Ye. Khain, "Permian Lithological Formations of the World," *Sov. geologiya,* Collection 54, 1956.
128. Ronov, A. B. and V. Ye. Khain, "History of Marine Sedimentation in the Middle and Upper Paleozoic in Connection with the Hercynian Stage of Crustal Development", *Sov. geologiya,* Collection 58, 1957.
129. Ruskol, Ye. L., "On the Origin of the Moon," *Astron. zhurnal,* Vol. 37, No. 4, 1960.
130. Ruskol, Ye. L., "On the Origin of the Moon," *International Symposium on the Study of the Moon. Abstracts of Reports,"* Pulkovo, 1960a.
131. Rukhil, L. B., "On Patterns in the Disposition of Folded Zones on the Earth's Surface," *Problemy sov. geologii,* Vol. VIII, No. 2, 1938.
132. Siarskiy, A. N., "Vulcanism and Solar Activity," *Circular of the L'vov Astronomical Observatory,* No. 34, 1958.
133. Stovas, M. V., "Critical Parallels of the Terrestrial Ellipsoid. Author's Abstract of Candidate's Thesis," Leningrad, 1955.
134. Stovas, M. V., "Geotectonics and Variability in the Rotation of the Earth," *Geological Collection of the L'vov Geological Society,* No. 5 - 6, 1958.
135. Stovas, M. V., "Potential of the Deforming Forces, and Its Variation in Connection with Variation in the Rotation of the Ellipsoid," *Herald of Leningrad State University, Mathematics, Mechanics and Astronomy Series,* No. 1, Leningrad, 1959.
136. Stovas, M. V., "Irregularity in the Rotation of the Earth as a Geotectonic Factor," *News of the All-Union Geographic Society,* Vol. 91, No. 4, 1959a.
137. Stovas, M. V., "Toward the Problem of the Formation of Planetary Abyssal Fractures in the Earth's Crust," *Dokl. AN SSSR,* Vol. 135, No. 1, 1960.
138. Strakhov, N. M., "Types of Climatic Zonation in the Post-Proterozoic Period of the Earth's History, and Their Significance for Geology," *Izv. AN SSSR, ser. geol.,* No. 3, 1960.
139. Sygayev, N. A., "Developmental Stages of Mobile Regions of the Earth's Crust," *Philosophic Questions of Natural Science,* Vol. III, Moscow, 1960.
140. Tamrazyan, G. P., "Destructive Earthquakes of the Trans-Caucasus, and the Phases of the Moon," *Izv. AN SSSR, ser. geofiz.,* No. 12, 1957.
141, Tverskoy, P. N., "Course in Geophysics," 3rd ed., Leningrad-Moscow, 1936.
142. Tillo, A. A., "Mean Dry-Land Altitude and Mean Ocean Depth in the Northern and Southern Hemispheres, and the Dependence of Mean Continental Altitude and Mean Ocean Depth Upon Geographical A Latitude," *Izv. Rus. geogr. o-va, (News of the Russian Geographic Society,* Vol. 25, No. 2, 1889.
143. Tikhomirov, V. V., "Toward the Problem of Crustal Development and the Nature of Granite," *Izv. AN SSSR, ser. geol., No.* 8, 1958.

144. Usov, M. A., "A Geotectonic Theory of the Self=Development of the Material of the Earth," *Izv. AN SSSR, ser. geol.*, No. 1, 1940.
145. Fedovor, Ye. P., "Concerning Slow Nonpolar Changes in Latitude," *Dokl. AN SSSR,* Vol. 91, No. 4, 1953.
146. Fesenkov, V. G., "Cosmogony of the Solar System," Moscow-Leningrad, 1944.
147. Frolov, N. V., "On the Origin of the Archean Granites of Eastern Siberia," *Izv. AN SSSR, ser. geol.*, No. 1, 1953.
148. Khabakov, A. V., "On the Basic Problems of the History of Development of the Lunar Surface," Moscow, 1949.
149. Khabakov, A. V., "Characteristic Features of the Lunar Surface. Basic Problems of the Genesis and Sequence of Development of the Lunar Formations," *The Moon,* 1960.
150. Khain, V. Ye., "On the Continuous-Discontinuous Flow of Tectonic Processes," *Izv. AN SSSR, ser. geol.*, No. 6, 1950.
151. Khain, V. Ye., "Geotectonic Principles of Oil Prospecting," Baku, 1954.
152. Khain, V. Ye., "Some Basic Problems of Modern Geotectonics," *Izv. AN SSSR,* No. 12, 1957.
153. Khain, V. Ye., "Philosophic Problems of the Geologic Sciences at their Modern Stage of Development," *Philosophic Problems of Natural Science,* Vol. III, Moscow, 1960.
154. Khain, V. Ye., "Origin of the Continents and Oceans," Moscow, 1961.
155. Khess, Kh. Kh. (1955), "Serpentinites, Orogenesis and Epeirogenesis," *The Earth's Crust,* Moscow, 1957.
156. Chebanenko, I. I., "Geotectonic Significance of the Earth's Rotation," *Dopovidi AN URSR,* No. 5, 1957.
157. Shatskiy, N. S., "On the Comparative Tectonics of North America and Eastern Europe," *Izv. AN SSSR, ser. geol.*, No. 4, 1945.
158. Shatskiy, N. S., "On the Origin of the Pachelm Depression," *Bulletin of the Moscow Society of Nature Lovers, Geology Division,* Vol. 60, (30), No. 5, 1955.
159. Shmidt, O. Yu. (1949), "Four Lectures on the Theory of the Origin of the Earth," 2nd ed., Moscow-Leningrad, 1950.
160. Shmidt, O. Yu., "The Origin and Early Evolution of the Earth," *Proceedings of the Geophysical Institute, USSR Academy of Sciences,* No. 26, (153), Moscow, 1955.
161. Shtille, G. (1955), "Modern Deformations of the Earth's Crust in the Light of Studies of Deformations Conducted in Earlier Periods," *The Earth's Crust,* Moscow, 1957.
162. Shubayev, L. P., "Lectures on General Earth Science," Leningrad, 1956.
163. Shubayev, L. P., "On the Zontaion of Relief," *Scientific Notes of the A. I. Gertsen Pedagogical Institute (Leningrad),* Vol. 151, 1958.
164. Shubert, T. F., "Essary of a Determination of the True Shape of the Earth," *Mem. Acad. of Science, of St. Petersburg,* 7th ed., Vol. I, No. 6, St. Petersburg, 1859.
165. Shchukin, I. S., "General Dry-Land Morphology," Vol. 2, Moscow-Leningrad, 1938.
166. Eygenson, M. S., "Solar Activity as a Geotectonic Factor," *Circular of the L'vov Astronomical Observatory,* No. 28, 1954.
167. Eygenson, M. S., " Solar Activity, Geodynamics and Geotectonics,"

Geological Collection of the L'vov Geological Society, No. 5 - 6, 1958.
168. Eygenson, M. S., "On Solar 'Control' of the Earth's Rotation," *Information Bulletin, Organization Committee of the International Geophysical Year, Ukrainian Academy of Sciences*, No. 1, 1958a.
169. Epil, E., Dzh. (1957), "Glacial Periods," *The Planet Earth,* Moscow, 1961.
170. Yuing, M. and F. Press (1955), "Geophysical Differences Between the Continents and the Oceanic Basins," *The Earth's Crust*, Moscow, 1957.
171. *Antarctica,* prepared by the American Geographic Society for the National Academy of Sciences, United States, National Committee International Geophysical Year, 1957 - 1958; Baltimore, 1958.
172. Appel, P., "A Treatise on Rational Mechanics", Vol. 4, No. 2, *Les figures d'equilibre d'une masse heterogene en rotation.* "Equilibrium Figures of a Rotating Heterogenous Mass", Paris, 1937.
173. Bauer, L. A., "Chief Results of a Preliminary Analysis of the Earth's Magnetic Field for 1922," *Terrestrial Magnetism,* Vol. 28, No. 1-2, Baltimore, 1923.
174. Bohm von Bohmersheim, A., "Flattening and Orogenesis", Leipzig and Vienna, 1910.
175. Bruckner, E., "The Solid Crust of the Earth and its Form", Vienna, 1897.
176. Bucher, W., "The Deformation of the Earth's Crust," Princeton, 1933.
177. Bucher, W., "Attempt at Analysis at the Great Movements of the Earth's Crust", *Geol. Rdsch.*, Vol. 30, No. 3/4, Stuttgart, 1939.
178. Bucher, W., "Megatectonics and Geophysics," *Trans. Amer. Geophys. Union,* Vol. 31, No. 4, 1950.
179. Cohen, C. J. and R. J. Anderle, "Verification of the Earth's 'Pear Shape' Gravitational Harmonic," *Science,* Vol. 132, No. 3430, 1960.
180. Conrad, V., "The Time Sequence of Earthquakes and Factors Initiating Quakes", *Handb. der Geophysik,* Vol. 4, No. 4, Berlin, 1932.
181. Dana, J., "On the Plan of Development in the Geologic History of North America," *Amer. J. Sci. and Arts,* Ser. 2, Vol. 22, 1956.
182. Darwin, G. H. (1877), "On the Influence of Geological Changes on the Earth's Axis of Rotation," *Scientific Papers,* Vol. 2, Cambridge, 1908.
183. Darwin, G. H. (1879), "Problems Connected with Tides of a Viscous Spheroid," *Scientific Papers,* Vol. 2, Cambridge, 1908.
184. Deecke, W., "A Fundamental Law of Orogenesis?", *Neues Jb. fur Mineralogie, Geologie und Palaontologie,* Vol. 2, No. 1-3, 1908.
185. Fourmarier, P., "Symmetry and Asymmetry in Large Units of the Earth", *Bull. Geol. Soc. Belgique,* No. 1 - 3, 1946.
186. Gill, J. E., "Original Crust in the Canadian Shield Area," *Bull. of the Geol. Soc. of America,* Vol. 62, No. 12, Pt. 2, 1951.
187. Gill, J. E., "Precambrian History of the Canadian Shield," *Bull. of the Geol. Soc. of America,* Vol. 64, No. 12, Pt. 2, 1953.
188. Green, W. L., " Vestiges of the Molten Globe as Exhibited in the Figure of the Earth, Volcanic Action and Physiography," Pt. 1,

London, 1875, Pt. 2, Honolulu, 1887.
189. Heiskanen, W., "Concerning the Influence of Tides on the Secular Acceleration of the Moon", *Ann. Acad. Sci. Fennicae*, Series A, Vol. 18, Helsinki, 1922.
190. Jeans, J., "Problems of Cosmogony and Stellar Dynamics, Cambridge,1919.
191. Kant, Immanuel (1754), "Investigation of the Question Whether the Earth has Undergone Change Since the Earliest Times of its Existence and if Rotation About its Axis Whereby it Produces Alternation of Day and Night", *Sammtl. Werke*, Vol. 1, Leipzig, 1867.
192. Kaula, W. M., "A Geoid and World Geodetic System Based on a Combination of Gravimetric, Astrogeodetic and Satellite Data," *J. of Geophys. Res.*, Vol. 66, No. 6, 1966.
193. King-Hele, D. G. and R. H. Merson, "A New Value for the Earth's Flattening Derived from Measurements of Satellite Orbits," *Nature*, Vol. 183, No. 4665, 1959.
194. Koch, L., "The Geology of Greenland", Berlin, 1935.
195. Kossina, E., "The Surface of the Earth", *Handb. der Geophysik*, Vol. 2, No. 3, Berlin, 1933.
196. Kuiper, G., "On the Origin of the Satellites and the Trojans," *Vistas in Astronomy*, Vol. 2, London and New York, 1956.
197. Kulp, J. L., "Origin of the Hydrosphere," *Bull. of the Geol. Soc. of America*, Vol. 62, 1951.
198. Laplace, P., "An Account of the System of the Moon", Vol. 1-2,Paris,1796.
199. Lapworth, C., "The Face of the Earth," Birmingham, 1894.
200. Leithauser, J.G., "Mappae mundi. The Intellectual Conquest of the World", Berlin, 1958.
201. Love, E. H., "The Gravitational Stability of the Earth," *Philos. Transactions of the Royal Soc.*, Vol. 207, London, 1907.
202. Meyermann, B., " The Rate of Contraction of the Earth's Radius from Astronomical Observation", *Zs. fur Geophysik*, Vol. 4, No. 3, 1928.
203. Meyermann, B., "Fluctuations in our Time Scale", *Ergebnisse der exacten Naturwissenschaften*, Vol. 7, Berlin, 1928a.
204. Nolke, F., "Geotectonic Hypotheses," Berling, 1924.
205. Nolke, F., "Concerning the Contraction Hypothesis and Certain Possibilities of Explanations Deriving Therefrom", *Geol. Rdsch*, Vol. 18, No. 2, 1927.
206. Oppenheim, S., "Concerning the Rotation and Precession of a Fluid Spheroid", *Astron. Nachrichten*, Vol. 113, No. 2701, Kiel, 1886.
207. Penck, A., "The Morphology of the Earth's Surface", Vol. 1, Berlin, 1894.
208. Pickering, W., "The Place of Origin of the Moon," *Amer. J. Geol.*, Vol. 15, 1907.
209. Pockels, F., "Variations in the Velocity of Rotation of the Earth as a Geological Factor, *Geol. Rdsch*, Vol. 2, 1911.
210. Prinz., "Concerning the Similarities Exhibited by Terrestrial and Planetary Maps.(Apparent twisting of the Planets)", *Ann. Observ. Brux.*, 1891.

211. Quiring, H., "Concerning the Problem of the Formation of the Crust and Mountains. Deceleration of the Rotation of the Axis of the Earth in the Force of Geological Periods as a Cause of Tectonic Movement", *Geol. Rdsch.*, Vol. 11, No. 5/6, 1921.
212. Ramsey, W., "On the Constitution of the Terrestrial Planets," *Monthly Not. Roy. Astr. Soc.*, Vol. 108, No. 5, 1948.
213. Ramsey, W., "The Nature of the Earth," *Monthly Not. Roy. Astr. Soc., Geophys. Suppl.*, Vol. 5, No. 9, 1949.
214. Reibisch, P., "A Principle of Formation of the Earth", *Jahresber. d. Ver. Erdkunde zu Dresden*, 1901 and 1905.
215. Richthofen, F., "Communications from the West Coast of North America. I. The Natural Distribution and Inner Relation of Volcanic Rock", *Zsh. d. deutsch. geol. Ges*, Vol. 21. No. 1, 1869.
216. Rothpletz, A., "Concerning the Possibility of Resolving the Conflict Between the Contraction and Expansion Theories", *Sitzungsber. Akad. Munchen*, Vol. 32, 1902.
217. Schiaparelli, G., "Astronomical and Physical Observation on the Axis of Rotation and on the Topography of the Planet Mars", Vol. 1-6, Rome, 1878-1899.
218. Schuchert, C., "Sites and Nature of the North American Geosyncline," *Bull. of the Geol. Soc. of America*, Vol. 34, 1923.
219. Simroth, H., "The Pendulation Theory", Leipzig, 1907.
220, Sitter, L. V., "On the Secular Accelerations and the Fluctuations of the Longitudes of the Moon, the Sun, Mercury and Venus," *Bull. Astron. Inst. Nederlands*, Vol. 4, No. 124, Haarlem, 1927.
221. Spitaler, R., "Earthquakes and Fluctuations of the Axis of the Earth", *Gerlands Beitr. zur Geophysik*, Vol. 42, No. 1-3, 1934.
222. Spitaler, R., "Earthquakes", *Dr. A. Petermanns Mitt. aus lustus perthes, Geogr. Anstalt.*, No. 9-10, 1936.

223. Stetson, H. T., "The Correlation of Deep-Focus Earthquakes with Lunar Hour Angle and Declination," *Science*, Vol. 82, No. 2135, 1935.
224. Stetson, H. T., "Correlation of the Frequencies of Seismic Disturbances with the Hour Angle of the Moon," *Publ. Bureau Central Seismol. International*, Ser. A, Fasc. 15, 1937.
225. Stearns, H., "Late Geologic History of the Pacific Basin," *Amer. J. of Sci.*, Vol. 243, No. 11, 1945.
226. Suess, E., "The Face of the Earth", Vol. 1-3, Vienna, 1883-1909.
227. Tisserand, F., "A Treatise of Celestial Mechanics" , Paris, 1891.
228. Taylor, W. B., "On the Crumpling of the Earth's Crust," *Amer. J. of Sci.*, Ser. 3, Vol. 30, 1885.
229. Thomson, W., and P. Tait, "Treatise on Natural Philosophy," Vol. 1, Pt. 2, Cambridge, 1883.
230. Umbgrove, J., "Structural History of the East Indies, Cambridge, 1949.
231. Veronnet, A., "Equilibrium Figures and Cosmotomy", Paris, 1926.
232. Veronnet, A., "Constitution and Evolution of the Universe," Paris,1927.
233. Worzel, J. and G. Shurbet, "Gravity Anomalies at Continental Margins," *Proc. U. S. Nat. Acad. Sci.*, Vol. 41, No. 7, 1955.
234. Wilson, J. T., "The Origin of Continents and Pre-Cambrian History," *Trans. Roy. Soc. Canada*, Vol. 43, Ser. 3, Sect. 4, 1949.

NASA-Langley, 1968 —— 13 F-533

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
WASHINGTON, D. C. 20546

OFFICIAL BUSINESS

FIRST CLASS MAIL

POSTAGE AND FEES PAID
NATIONAL AERONAUTICS AN
SPACE ADMINISTRATION

POSTMASTER: If Undeliverable (Section 158 Postal Manual) Do Not Returı

"The aeronautical and space activities of the United States shall be conducted so as to contribute . . to the expansion of human knowledge of phenomena in the atmosphere and space. The Administration shall provide for the widest practicable and appropriate dissemination of information concerning its activities and the results thereof."

— NATIONAL AERONAUTICS AND SPACE ACT OF 1958

NASA SCIENTIFIC AND TECHNICAL PUBLICATIONS

TECHNICAL REPORTS: Scientific and technical information considered important, complete, and a lasting contribution to existing knowledge.

TECHNICAL NOTES: Information less broad in scope but nevertheless of importance as a contribution to existing knowledge.

TECHNICAL MEMORANDUMS: Information receiving limited distribution because of preliminary data, security classification, or other reasons.

CONTRACTOR REPORTS: Scientific and technical information generated under a NASA contract or grant and considered an important contribution to existing knowledge.

TECHNICAL TRANSLATIONS: Information published in a foreign language considered to merit NASA distribution in English.

SPECIAL PUBLICATIONS: Information derived from or of value to NASA activities. Publications include conference proceedings, monographs, data compilations, handbooks, sourcebooks, and special bibliographies.

TECHNOLOGY UTILIZATION PUBLICATIONS: Information on technology used by NASA that may be of particular interest in commercial and other non-aerospace applications. Publications include Tech Briefs, Technology Utilization Reports and Notes, and Technology Surveys.

Details on the availability of these publications may be obtained from:

SCIENTIFIC AND TECHNICAL INFORMATION DIVISION

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

Washington, D.C. 20546